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Users'
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May 1978

Manned Maneuvering Unit

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MANNED MANEUVERING UNIT

Prepared by:

J. A. Lenda
Systems Project Engineer
Martin Marietta

Approved by:

J. Josephson

J. T. Josephson
Program Manager
Martin Marietta

E. J. Nitsch

E. J. Nitsch
Contract Technical Monitor
NASA–Johnson Space Center

C. E. Whitsett

C. E. Whitsett
Subsystem Manager
NASA–Johnson Space Center

MARTIN MARIETTA CORPORATION
P.O. BOX 179
Denver, Colorado 80201

FOREWORD

This document was prepared as part of the Manned Maneuvering Unit Preliminary Design Contract to provide applications data and a capabilities description for orbital mission planning and studies. The document was prepared by Martin Marietta Corporation and is submitted in accordance with Exhibit "A", Statement of Work, paragraph 3.3.2 of Contract NAS9-14593. Comments or questions concerning this document should be directed to the following personnel:

J. T. Josephson, Martin Marietta Aerospace--(303) 973-3000;

J. A. Lenda, Martin Marietta Aerospace--(303) 973-3000;

C. E. Whitsett, NASA-Johnson Space Center--(713) 483-5536.

ABBREVIATIONS AND ACRONYMS

AAH	automatic attitude hold
ASMU	automatically stabilized maneuvering unit
CEA	control electronics assembly
CM	center of mass
DCM	displays and controls module, of EMU
ΔP	delta pressure
ΔV	delta velocity, equivalent in translation
EMU	extravehicular mobility unit
EVA	extravehicular activity
fps	feet per second
FSS	flight support station
GN_2	gaseous nitrogen
kg	kilograms
LDEF	Long Duration Exposure Facility
MMU	manned maneuvering unit
PLSS	primary life support system
psi	pounds per square inch
RHC	rotational hand controller
RMS	remote manipulator system (orbiter)
STS	Space Transportation System
THC	translational hand controller
t_{min}	minimum time curve, for MMU translation

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1.0 INTRODUCTION

The Space Shuttle will provide an unprecedented opportunity to extend and enhance the crew's inherent capabilities in orbit by allowing them to operate effectively outside of their spacecraft by means of extravehicular activity (EVA). For this role the Shuttle crew will have a new, easier to don and operate space suit with integral life support system, and a self-contained propulsive backpack (see Fig. 1). The backpack, called the manned maneuvering unit (MMU), will allow the crew to operate beyond the confines of the Shuttle cargo bay and fly to any part of their own spacecraft or to nearby free-flying payloads or structure. This independent mobility will be used to support a wide variety of activities including free-space transfer of cargo and personnel, inspection and monitoring of orbital operations, and construction and assembly of large structures in orbit.

The MMU is being developed by the Space Shuttle program office and will be available to Shuttle users as a standard service. The projected MMU support capabilities are based on the successful orbital tests conducted during the Skylab missions as part of the M509 maneuvering unit experiment, and the current design was derived through an extensive research and technology development program at the Johnson Space Center. The MMU is operated through separate hand controllers for inputting the pilot's translation and rotation maneuver commands to the cold gas thruster system. Other design features include automatic attitude stabilization, work area lights, auxiliary power outlets, and attachment provisions for cargo or worksite restraints. The maneuvering unit is stowed for launch in the forward end of the Shuttle cargo bay at a flight support station which is also used for MMU donning/doffing and servicing on-orbit.

The purpose of this document is to provide information for the potential MMU user to assess the utility of the MMU for specific applications, and to provide guidance for developing preliminary plans for MMU operations in support of those applications. Section 2.0 of this document describes several examples of MMU utility, and Section 3.0 discusses user charges. The MMU functional and operating characteristics are presented in Sections 4.0 and 5.0. Consumables parametrics are illustrated in Section 6.0. Appendix A provides a more detailed technical description of the MMU, including mass properties data. A listing of general EVA guidelines is provided for reference in Appendix B.

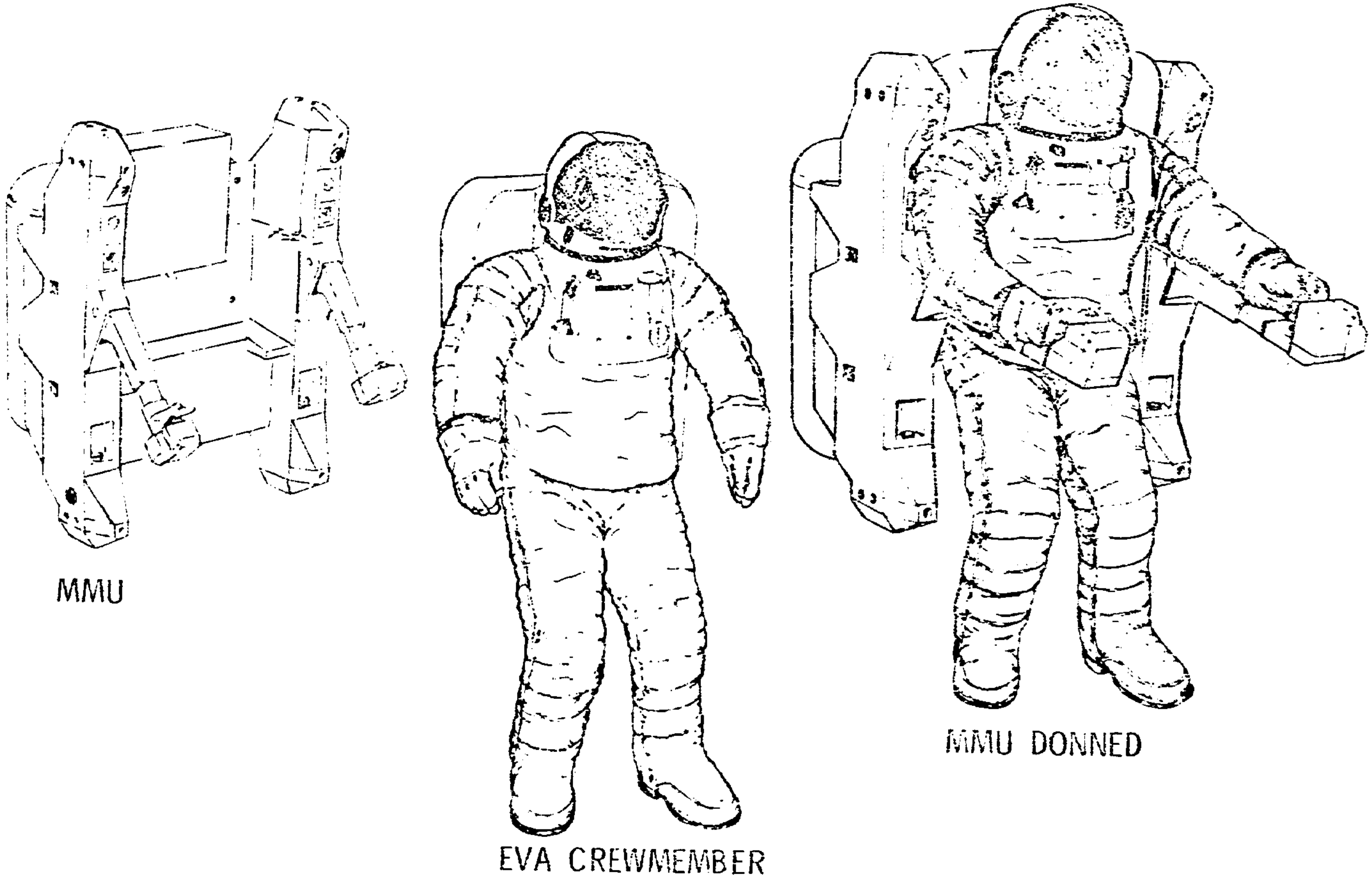

Figure 1 Space Shuttle Manned Maneuvering Unit (MMU)

2.0 MMU EVA UTILITY

The MMU is provided by NASA as Space Shuttle EVA support equipment and is available for use by any payload on any scheduled mission beginning with operational flights in 1981. It can be used for EVA support, orbital operations support, and EVA rescue operations. Specific tasks which can be performed with the assistance of the MMU are limited only by the functional capabilities of the unit and by the EVA guidelines which apply to the STS program. Typical tasks which the MMU can support are listed below.

Shuttle EVA Support

a. External inspection of the Orbiter;

b. Documentary photography/television.

Shuttle Payload Support

a. Payload deployment or retrieval;

b. Adjustment of instruments;

c. Retrieval and replacement of film, coatings, emulsions;

d. Servicing free-flying payloads;

e. Replacement of failed modules;

f. Cleaning sensors and lenses;

g. Assembly of large structures;

h. Routing of cables or lines between discontinuous points;

i. Application of spray coatings;

j. Removal of contamination protective covers;

k. Malfunction assessment and corrective action.

Crew Rescue Support

a. Support the transfer of crewmembers and equipment in a rescue situation involving a stable orbiter;

b. Provide a means for the transfer of crewmembers and equipment in a rescue situation involving a tumbling orbiter.

The following illustrations depict various tasks which an EVA crew member can perform with the support of the MMU. They are presented here as examples of MMU utility, and to aid in the generation of other task possibilities by potential users.

Figure 2 shows a crewmember in a MMU approaching a satellite for inspection. The crewmember might also photograph the satellite, retrieve a sample, correct a deployment malfunction, or stabilize the satellite for retrieval by the Orbiter.

A repair operation being conducted on a beam builder is depicted in Figure 3. One crewmember utilizes a reactionless power wrench to remove the panel bolts, while the second crewmember photographs the procedure. The first crewmember uses only a waist tether and handhold to maintain position, and has the MMU control arms folded down for access at the work area. Power for the wrench is supplied from one of the MMU ancillary outlets. The second crewmember is in automatic attitude hold while photographing the repair operation.

In Figure 4, a crewmember in a MMU is transporting an experiment tray to the Long Duration Exposure Facility (LDEF) for placement into the structure of the satellite. A second MMU-equipped crewmember waits at the LDEF to assist. The experiment tray may weigh as much as 175 lbs (80 kg) and can be easily transported by the MMU. Note that the figure shows the MMU cargo attachments at the side and front being utilized. Figure 5 shows the two crewmembers positioning the tray for placement in the LDEF structure. Such a technique has the advantage of minimizing potential contamination of the experiments or spacecraft from the Orbiter RCS, by maintaining a standoff distance of several hundred yards. The MMU thus allows normal servicing to be accomplished on the LDEF without approach or capture by the Orbiter. In those instances where retrieval of LDEF is required, the MMU can be utilized to stabilize the spacecraft, if necessary, prior to capture by the remote manipulator system (RMS) or after an unsuccessful capture attempt has imparted tumble rates to the LDEF.

Figure 6 illustrates a crewmember carrying a film/tape cassette for changeout in a satellite. A simple waist tether is utilized to carry the item. The task of replacing the cassette in the satellite could be easily performed without the use of additional worksite restraints. A more extensive servicing task, such as the replacement of an equipment module in a satellite, would require additional worksite restraints. Figure 7 shows a crewmember utilizing a foot restraint to provide support. Most payloads will likely contain such an integral foot restraint system to facilitate servicing tasks; however, the MMU is capable of transporting such a restraint to the work site for placement into a receptacle on the satellite structure. The figure also depicts the MMU control arms folded down to allow closer access to the work area, and shows the MMU floodlights being used to illuminate the work site.

Two crewmembers in MMUs are shown transporting a beam across a structure in Figure 8. The crewmembers coordinate their movements by voice communication and can easily position the beam, which is very lightweight, within the structure. For example, the beam shown is 150 feet (50 meters) long and weighs approximately 11 lbs (5 kg). The crewmembers are shown performing a beam alignment task in Figure 9. The crewmember at the theodolite is directing cable tension adjustments being made by the second crewmember.

Figures 10 and 11 illustrate the utility of the MMU for Shuttle rescue in the case where the disabled vehicle is not stabilized. In such a situation, the MMU is the only practical method of effecting rescue. As the figures illustrate, tangential velocities at the hatch may exceed several feet per second because of the distance from the side hatch of the Orbiter to the vehicle center of gravity. Rescue with the RMS will be difficult because of this velocity and because of the limited reach envelope of the RMS. Rescue with the MMU allows the second Orbiter to stand off at a safer distance while the rescue crewmember maneuvers to achieve the required velocity. A Shuttle rescue operation is shown in

Figure 12. The crewmember in the MMU carries another crewmember in the rescue sphere. The MMU can also support repair or salvage of an abandoned Orbiter.

The MMU would be invaluable to revisit Skylab for the retrieval of material samples because of its ability to maneuver to any position on the vehicle. A safe approach for inspection of Skylab can be made from the Orbiter using the MMU. An early revisit mission, where the Orbiter has been docked to Skylab, is depicted in Figure 13. Two crewmembers in MMUs are shown approaching the Skylab workshop with a section of a meteoroid/thermal shield. Such a shield may be required to protect the workshop environment for planned reuse missions in Skylab.

Small free-flying satellites or experiment packages can be deployed or retrieved by a crewmember in the MMU, as shown in Figure 14. This technique can be utilized as a planned operation or as a contingency procedure in the event of failure to achieve deployment/retrieval with the RMS. For low cost payloads or experiment packages the MMU-equipped crewmember could deploy the equipment at a specific distance from the Orbiter, perform activation procedures on the experiment (e.g., extend sensors, remove covers) and return to retrieve the package after sufficient data have been collected. As a contingency deployment/retrieval technique for satellites or experiments, the MMU provides a higher probability of complete mission success.

Figure 15 depicts several crewmembers stringing support cabling through a large structure. The cable reels are attached to the MMU at the front of the control arms, leaving the crewmember's hands free to operate the hand controllers. Connecting crossmember cables may be more easily accomplished with the aid of the MMU because it can safely maneuver around and within the complex structure, and because stringing cables is a task which is very difficult to automate.

Maneuvering unit use in the assembly of large antennae, as shown in Figure 16, can demechanize the assembly procedure, thus reducing program costs and achieving a higher probability of complete mission success.

This is especially true in early demonstration flights of erectable structures when operational procedures must be proven.

Figure 17 shows potential MMU support of the space construction automated fabrication experiment. Specific activities could include crew transfer to and from the beam builder assembly, visual inspection and surveillance of beam construction, installation of thermopile detectors and accelerometers, support of dynamic and thermal response experiments, and assistance in demonstrating beam cap and cord repair. In this application, most beam fabrication is performed continuously while being controlled and monitored by the crew inside the Orbiter. EVA is required to perform tasks such as installing subsystems and sensors and connecting electrical cables, where the infrequent occurrence of these activities does not justify the complexity of automated techniques.

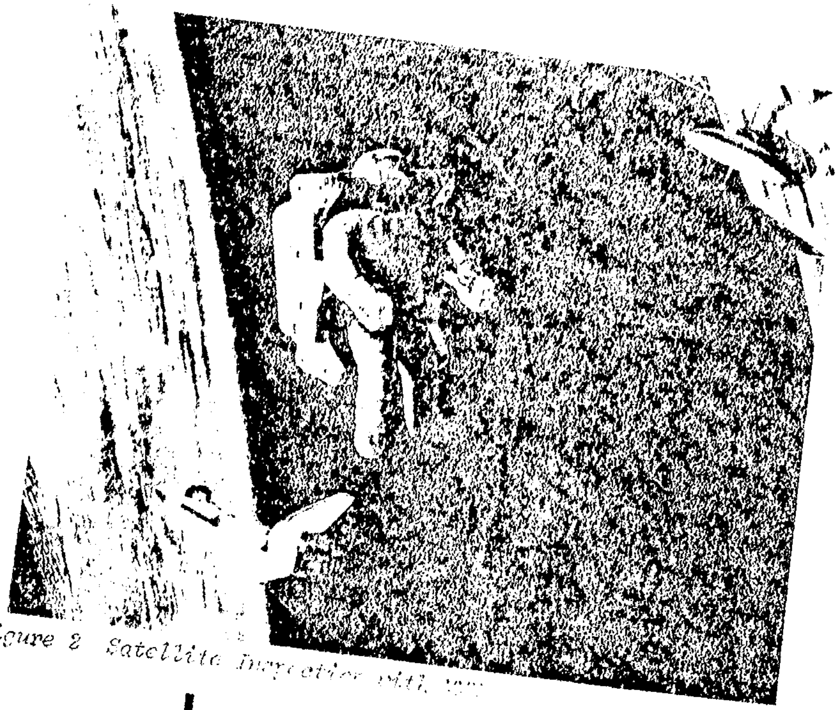

Figure 2 Satellite Inspection with [illegible]

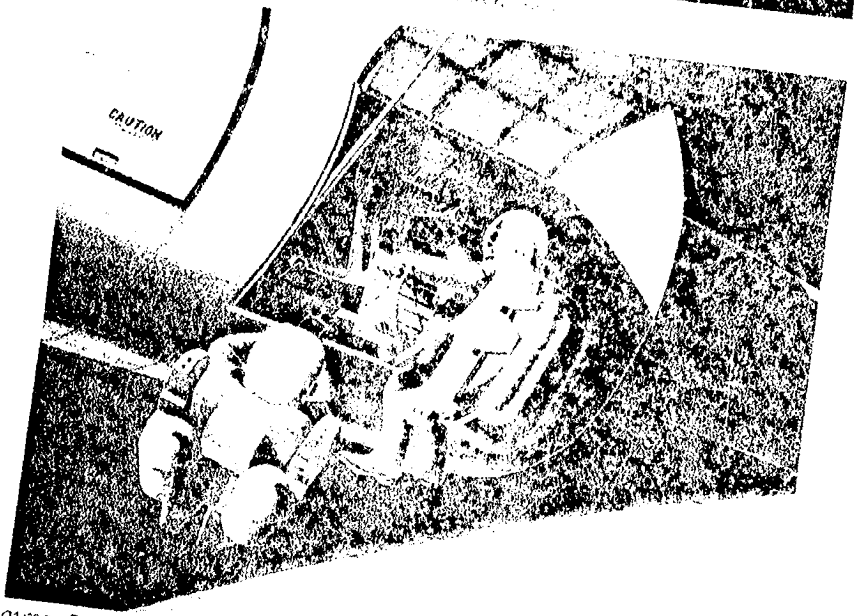

Figure 3 Beam Builder Repair

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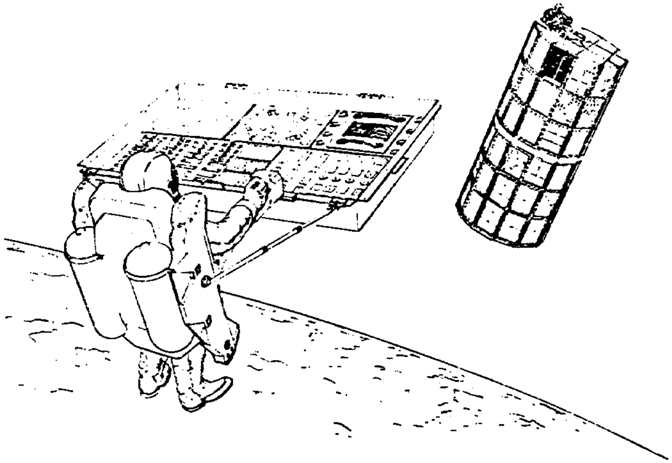


Figure 4 Experiment Replacement with MMU

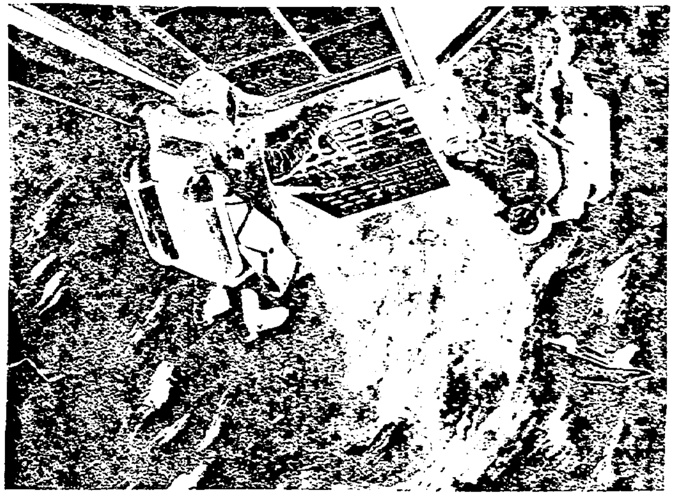


Figure 5 LDEF Servicing with MMU

Figure 6 MMU Carrying Small Equipment Item

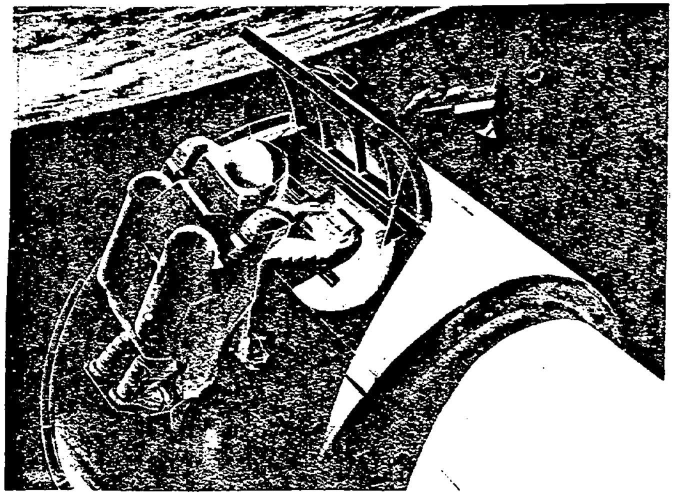


Figure 7 Satellite Servicing with MMU

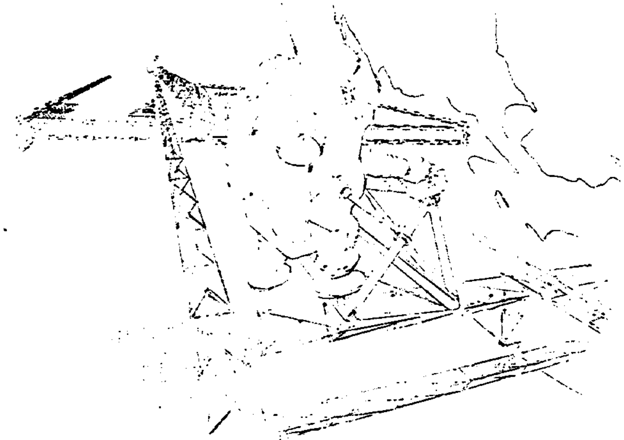


Figure 8 MMUs Transporting Beam

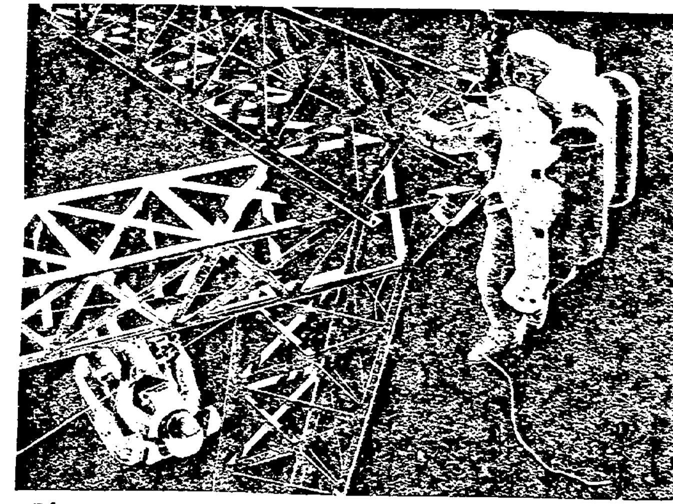
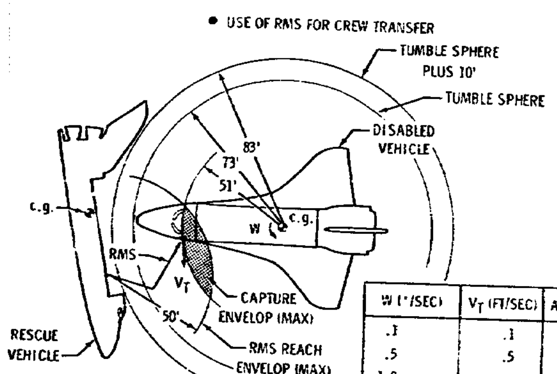


Figure 9 Structure Alignment Task



W (°/SEC)	V_T (FT/SEC)	A (FT/SEC^2)
.1	.1	.00
.5	.5	.00
1.0	.9	.02
3.0	2.7	.14
6.0 (1 RPM)	5.3	.56
12.0 (2 RPM)	10.7	2.24

Figure 10 Rescue from Unstabilized Orbiter with RMS

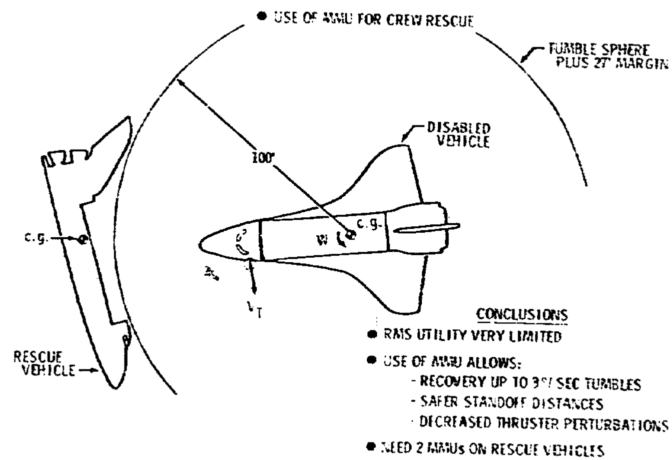


Figure 11 Rescue from Unstabilized Orbiter with MMU

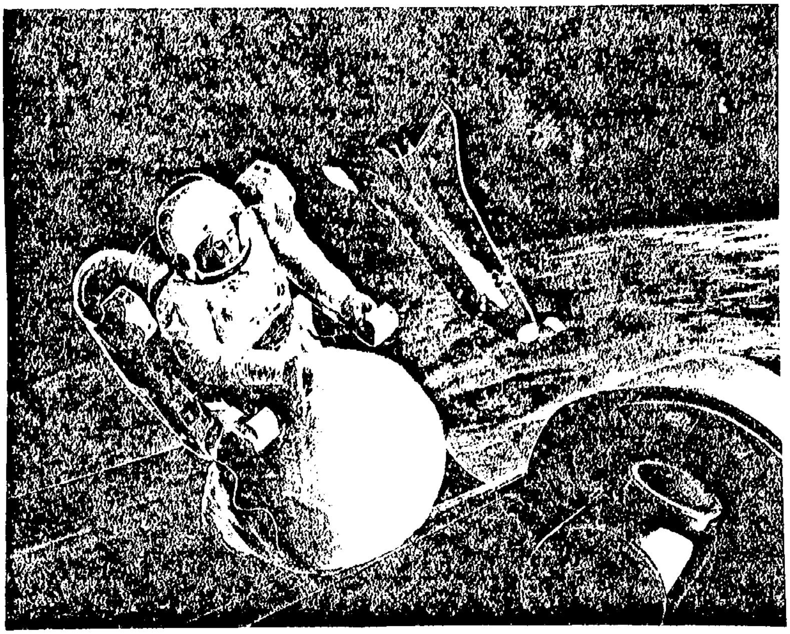


Figure 12 Shuttle Rescue with MMU

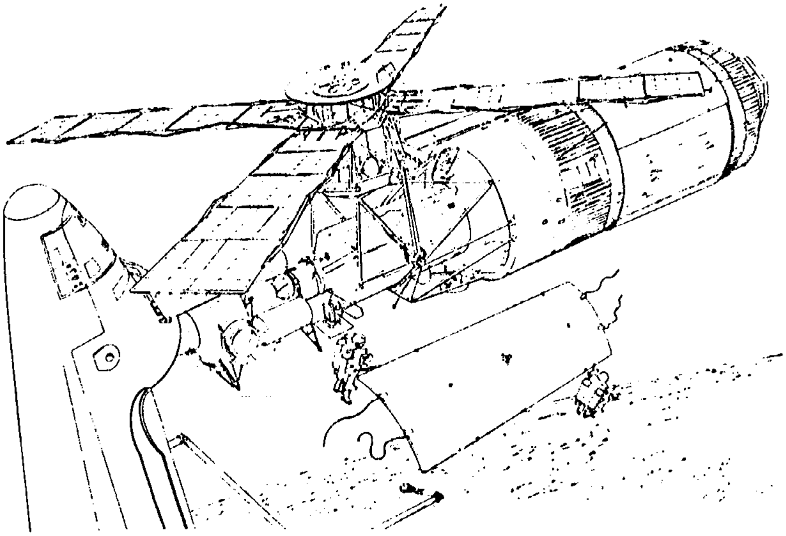


Figure 13 Skylab Reuse Mission

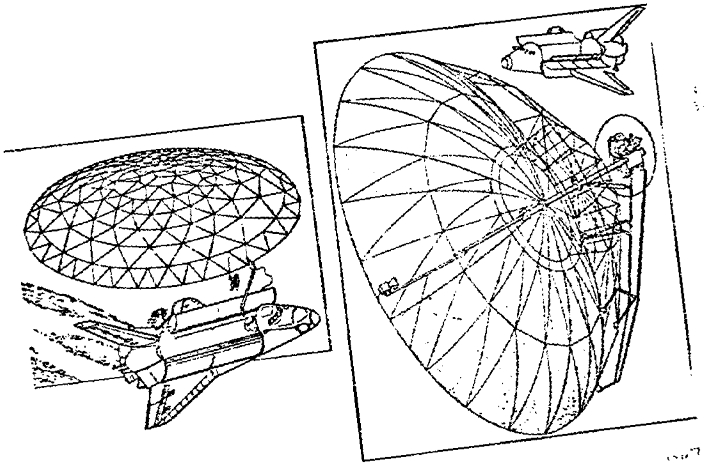


Figure 14 Deploy/Retrieve Small Free-Flying Satellite with MMU

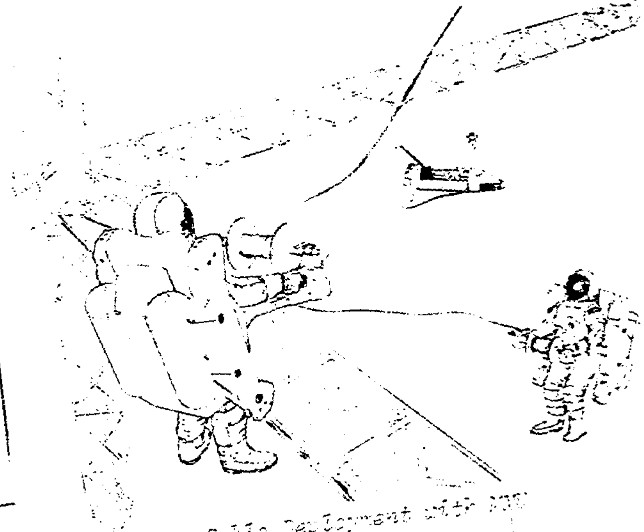


Figure 15 Cable Deployment with MMU

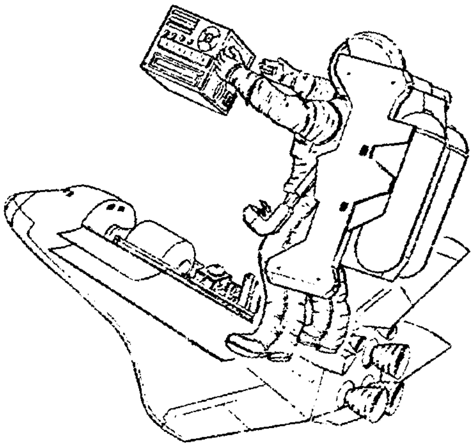


Figure 16 MMU Use in Assembly of Large Antennas

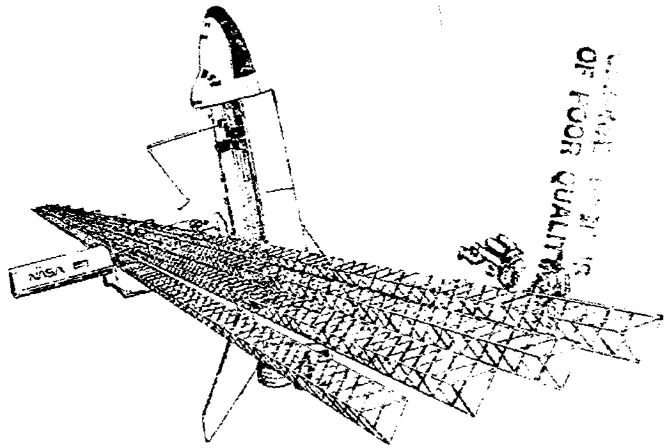


Figure 17 [illegible] Construction with MMU

3.0 USER CHARGES

The MMU development will be funded by the Shuttle program and users will be charged only a nominal fee for each mission on which the MMU is employed. This fee is in addition to other launch costs charged to payloads according to established NASA policy. The MMU user fee includes all mission costs, including both flight and ground operations.

Current estimates of user charges for Shuttle EVA are in the range of $60,000 to $100,000 per mission. Use of an MMU during EVA would put the user cost in the upper end of this range, with exact charges dependent on the specific tasks to be performed. Within this price range NASA will provide the following functions and hardware: manned maneuvering unit and support equipment, extravehicular mobility unit and communications equipment, MMU mission planning, flight operations support, crew activity planning, and training. Mission-unique support equipment and training are not included in this price range.

NOTE TO USERS: As additional STS costing information becomes available, this section will be expanded and updated. Additional cost figures will be forwarded to users as soon as those figures are generated by the STS and MMU programs.

4.0 FUNCTIONAL CAPABILITIES

4.1 Maneuvering Capability

The Manned Maneuvering Unit is operated directly by the crewmember, using the translational and rotational hand controllers. Six-degree-of-freedom (3 axes in translation, 3 axes in rotation) command authority is maintained in response to manual inputs. The MMU is fail-safe, such that any single failure does not preclude the crewmember from returning to the Orbiter with full six-degree-of-freedom control. Table 1 summarizes the flight characteristics of the MMU, and a more detailed technical description is contained in Appendix A of this document.

Table 1 MMU Flight Characteristics

- Six-Degrees-of-Freedom Control Authority
- Spacecraft-type Piloting Logic
  - 3-Axis Translational Controller (Left Hand)
  - 3-Axis Rotational Controller (Right Hand)
  - Independent or Multiple Axis Commands
  - Pulse or Continuous Commands
- Manual (Direct) Translation and Rotation Control
- Automatic Attitude Hold
  - Deadband Adjustable ± 0.5 to $\pm 2.0^{\circ}$
  - Inertial Drift less than 0.01°/sec
- Response
  - Translational Acceleration 0.3 ± 0.05 ft/sec^2
  - Rotational Acceleration $10.0 \pm 3.0^{\circ}$/sec^2
- Audio Feedback for Thruster Operation

4.2 Work Site Aids/Ancillary Equipment

The MMU contains provisions to attach cargo or equipment for transport during maneuvers. These attachments allow the crewmember's hands to remain free to operate the MMU hand controllers. Three types of attachments are available. Telescoping, lockable arms with grappling end effectors (see Fig. 18) can be extended from each side of the MMU to hold cargo in front of and below the hand controllers. Soft tethers can be attached to the cargo and to the pressure suit waist ring, or the side of the MMU. Finally, attachment mechanisms can be mounted at the end of each hand controller housing (see Fig. 19) to carry a smaller cargo item directly in front of the crewmember's hands.

These attachment provisions are generally intended to allow easy transport of relatively small (less than 50 lbs) cargo items. The MMU system is capable, however, of transporting larger masses (up to several hundred pounds) in specific cases. The MMU control system compensates for changes in center of gravity and the torques which result from attaching such additional cargo. Exact limiting criteria are dependent on the total task requirements (e.g., distances, time constraints), in addition to the cargo mass and location.

The electrical system of the MMU provides auxiliary power which can be utilized to operate tools or other equipment at the task site, once translation to the site has been accomplished. Two power outlets supply 28V DC at 2 amps maximum; each outlet is operated by a switch accessible to the crewmember in flight. In addition, a floodlight which provides local work site illumination is mounted over each shoulder of the crewmember in the MMU (see Appendix A, Figure A-2). Section 6.2 of this guide gives details on power consumption parametrics.

Tethers can be utilized to establish a soft attachment between the crewmember/MMU and work site (see Fig. 20). A temporary system is also available to establish a more rigid attachment between the MMU and the work site. This system is designed to allow the crewmember to apply

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Figure 15 MMU Cargo Attachments - Side Grappling

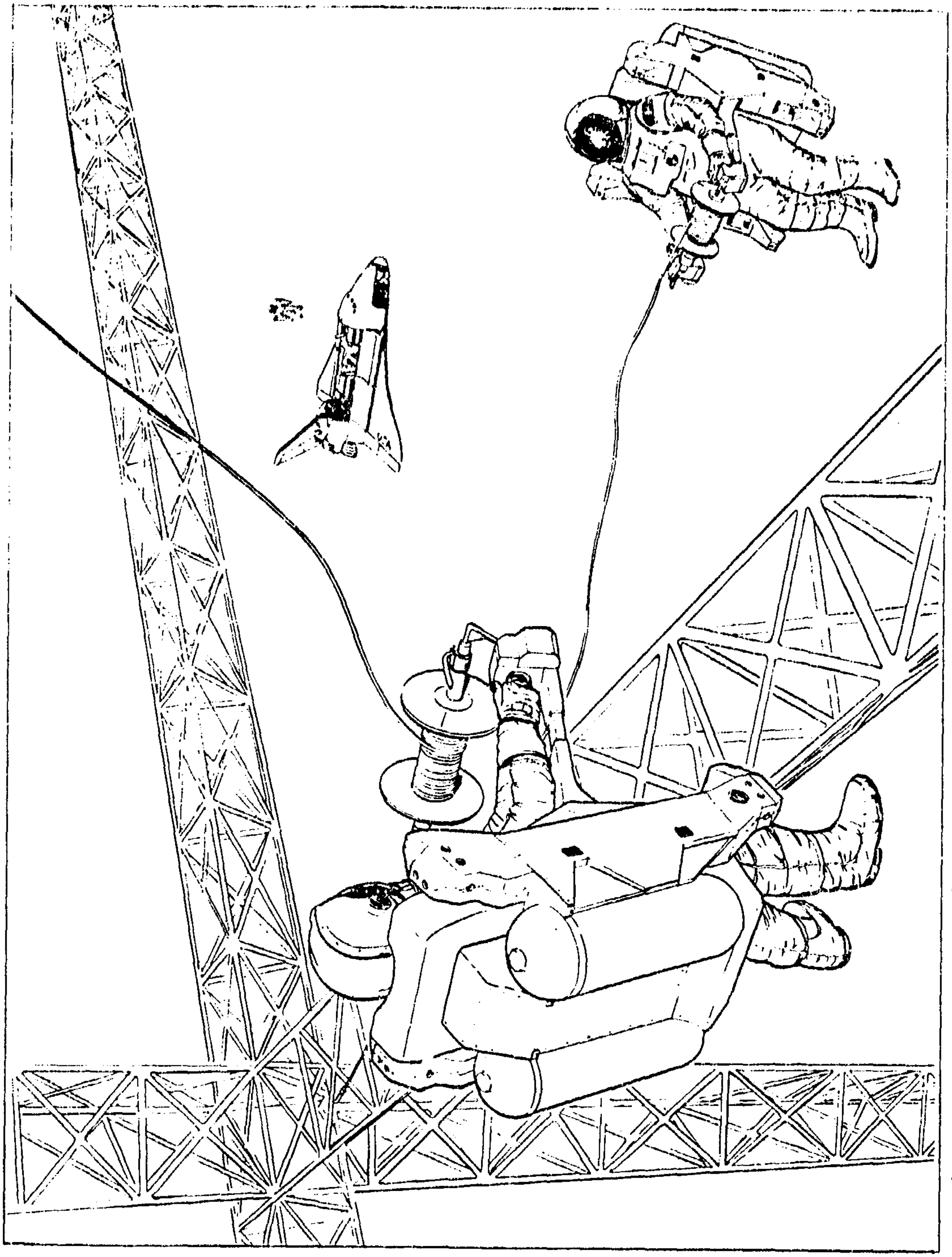

Figure 12 MMU Cargo Attachments - Front Mount

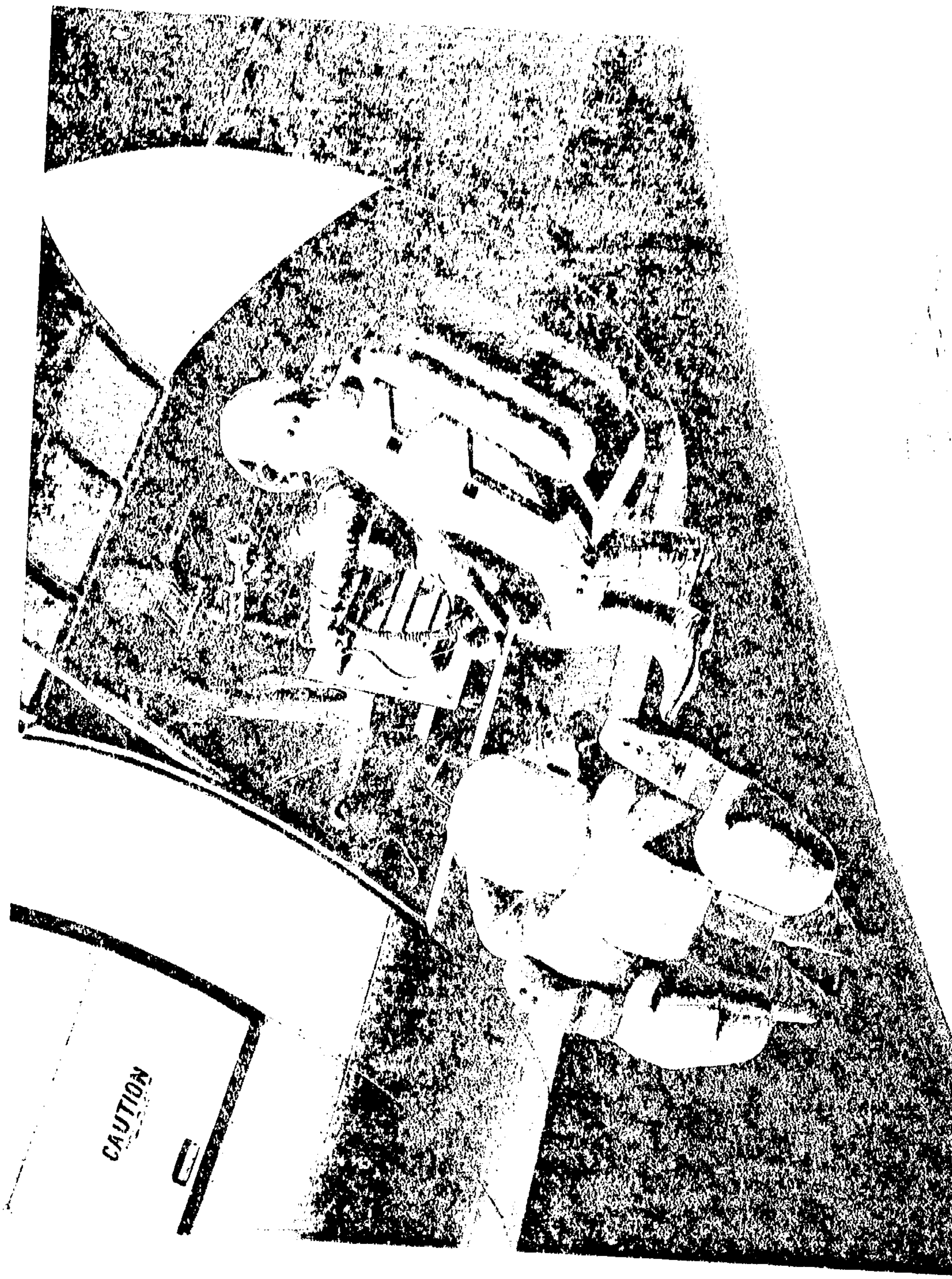

Figure 22 Use of Soft Tether Between MMU and Work Site

moderate forces at the work site without generating intolerable reactions or torques (see Fig. 21). It should be noted that additional work site dedicated restraints may be required if large forces or torques must be applied by the crewmember at the site. These restraints must be supplied by the user, or be built into the work site. A variety of standard Shuttle equipment is available for such support (see JSC-10615, "Shuttle EVA Description and Design Criteria").

The arms on which the MMU hand controllers are mounted can be folded down to provide clearance for the crewmember to approach the work site more closely. Figure 22 shows an application of this capability.

Additional functional capability can be kitted into the MMU if required by a specific operational mission. Additional propellant tanks and navigation aids can be attached to the baseline MMU system to allow extended excursions farther away from the Orbiter vehicle. Although design concepts for these kits have not been finalized, potential MMU users should be aware that such capability will become available as part of the basic MMU configuration as the Shuttle flight program progresses.

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Figure 21 MMU Temporary Restraint System

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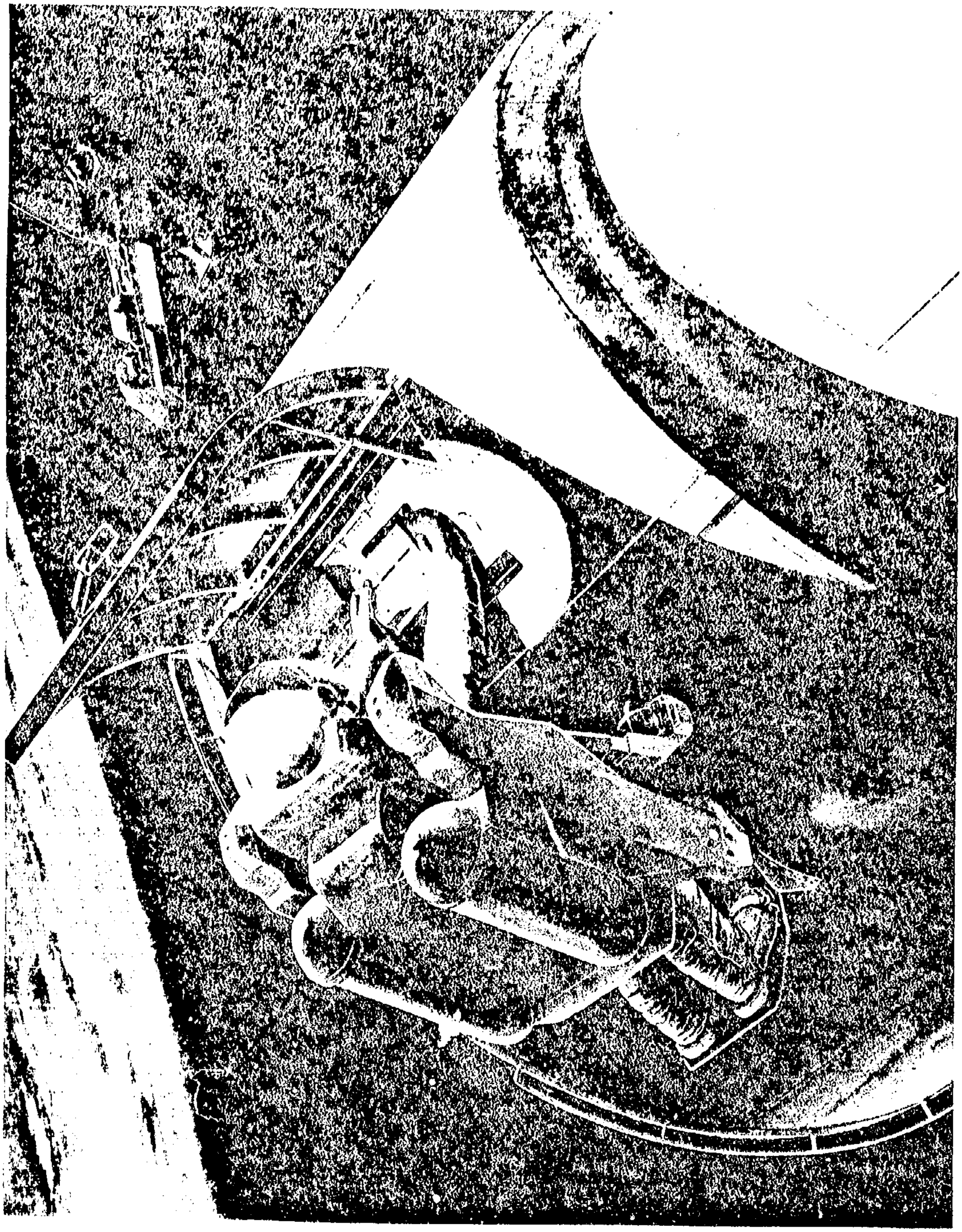


Figure 22 MMU Arms Folded Down to Provide Access to Work Site

4.3 Operational Guidelines

The baseline MMU design provides potential users with a versatile vehicle to perform a wide variety of orbital activities. Operations with the MMU are governed by guidelines and constraints resulting from STS mission rules, MMU design philosophy, and the flight experience of the Skylab M509 maneuvering system. All MMU operations must be planned within these guidelines and those described in Appendix B.

Extravehicular activities, including those which utilize the MMU, are conducted by crewmembers wearing the EMU, the pressure suit/life support assembly. Information regarding the EMU, prebreathing times, and performance characteristics can be obtained by referring to applicable EMU documentation. The major operative constraint of the EMU on the MMU is the six-hour limitation of life support consumables for any single EVA.

Although the MMU cold gas propulsion system is essentially noncontaminating, the EMU life support system does vent water vapor to space (approximately 1 lb water per hour). In almost all cases for specific payload operations, this level and type of contamination is well within acceptable limits.

Typically, EVA operations are conducted by the Orbiter pilot and by the mission specialist, although other trained personnel are not precluded from performing EVA. It is the user's responsibility to insure these personnel are familiar with the tasks to be performed. Normally, real time training exercises will not be conducted. Detailed descriptions of the procedures and equipment to be utilized--other than the MMU itself--will be required, however. Flight training for the MMU will be the responsibility of the Shuttle program.

The MMU cannot be effectively utilized as a stable platform from which large forces and torques can be exerted; that is, the MMU should not be considered a mechanism through which large forces or torques can be reacted to do work. Additional restraints, as described in Section 4.1 above, are required in such cases. The MMU can be utilized however, to counter light loads such as might occur during simple tasks. The MMU can also effectively transport massive objects when operating free of external forces (see Section 6.0).

5.0 OPERATING SEQUENCE

5.1 Donning and Egress

For normal orbital operations during which the MMU will be utilized the EMU-equipped crewmember egresses from the airlock of the Orbiter at the forward end of the payload bay. The primary life support system (PLSS) backpack provides the proper environment within the pressure suit. The crewmember translates via handholds to the MMU Flight Support Station (FSS) which is located at the forward end of the payload bay near the airlock (see Fig. 23).

The entire sequence of egress tasks, summarized below, will require no more than 20 minutes to perform.

- Egress from airlock into payload bay at MMU/FSS location.
- Temporarily stow any support equipment such as cameras, tools, portable work stations, or repair kits.
- Reconfigure MMU from the launch/entry configuration for use in orbital operations, and prep for donning.
- Verify propellant supply tank pressures, and perform visual inspection of MMU.
- Attach EVA support equipment to the MMU.
- Don the MMU and verify all interfaces.
- Power up the MMU.
- Verify instrumentation and conduct checkout of MMU systems.
- Release MMU from FSS.
- Perform in-flight checkout of control systems.
- Proceed with MMU/EVA flight operations.

After transferring to the FSS, the crewmember performs initial visual checkout of the MMU while facing the unit. Battery replacement, if required, is performed at this time (see Section 5.4). The crewmember dons the MMU by turning around to face the centerline of the

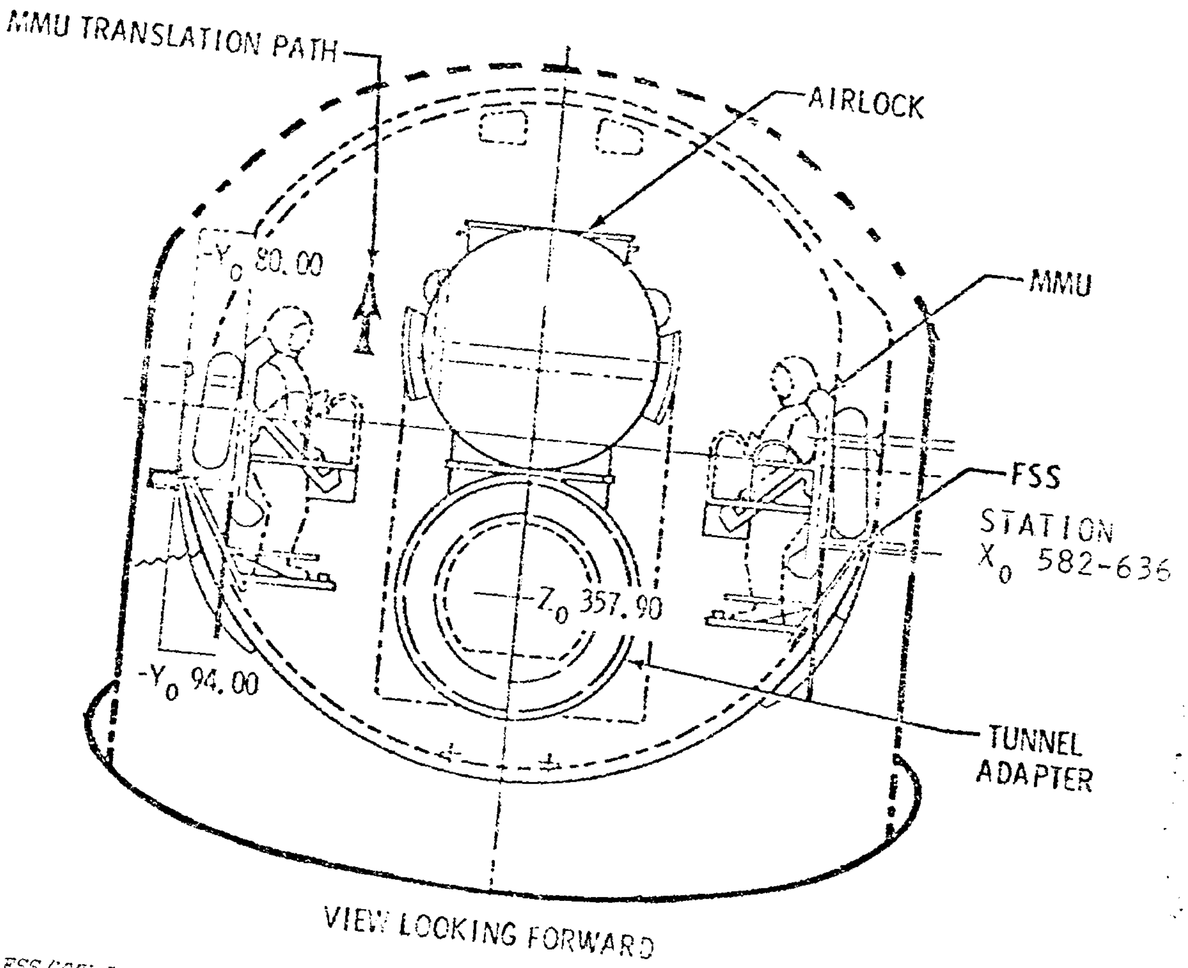


Figure 23 FSS/MMU Locations in Cargo Bay with Airlock/Tunnel Adaptor

payload bay and backing into the MMU mounted on the FSS (see Fig. 24a).

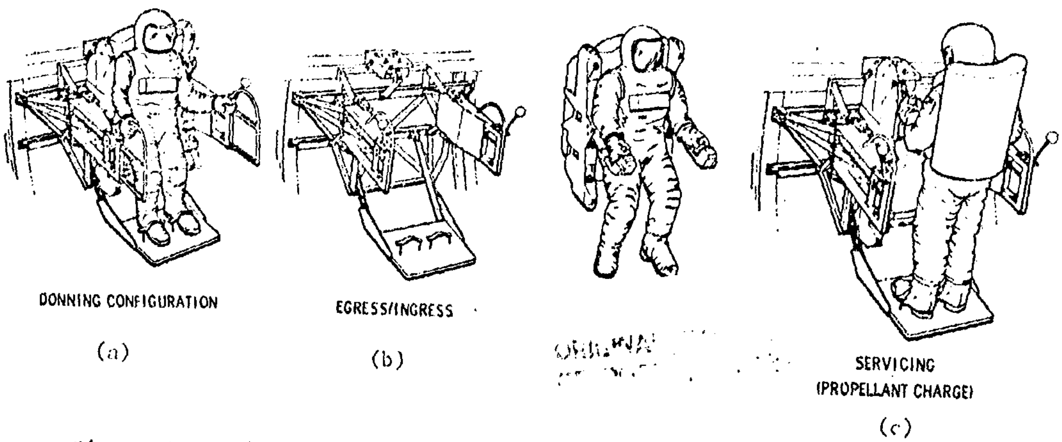


Figure 24 MMU Activities at FSS

Latches on each side (inside) of the thruster towers engage striker plates on each side of the PLSS. At this point the data interface (via an optical connection) between the MMU and the EMU is established, and the crewmember can utilize the display and controls module (DCM) of the EMU to verify MMU power and fuel quantities (see Appendix A).

The astronaut/EMU/MMU system is released from the FSS by manual operation of the release levers located near each FSS handrail (see Fig. 24b). The crewmember then maneuvers upward out of the payload bay. An operational check of the MMU system is accomplished in the immediate vicinity of the Orbiter, prior to beginning the scheduled operations. This check would involve commanding brief translations and rotations in all six axes, and powering up the rate gyros to verify attitude hold operation.

It should be noted that although several airlock, tunnel, and docking module configurations are possible in the forward end of the payload bay, the FSS location and the procedures to utilize the MMU remain the same. A specific envelope (the forward 48 inches of the payload bay) is reserved ($X_o 579$ - $X_o 627$) when EVA operations are planned on any mission.

5.2 Flight Mode

Control of the MMU in the flight mode is direct. The astronaut commands accelerations in six axes by displacing the hand controller grips as required. Automatic attitude hold can be initiated or inhibited as required. The only interface between the astronaut/EMU/MMU system and the Orbiter vehicle during EVA is a voice communications link which is part of the EMU. The crewmember utilizes only visual cues to judge relative velocity and distance during MMU maneuvers. During flight, the crewmember utilizes the displays on the DCM to continually assess MMU fuel and power consumption. The mission assignment can then be accomplished as defined by the user (see Section 2.0).

5.3 Ingress and Doffing

On completion of the tasks the crewmember returns to the Orbiter and approaches the FSS. By backing into the support structure, the crew member engages latches between the MMU and FSS. Latches which engage the MMU to the PLSS are then released by the crewmember to allow passage back through the airlock into the Orbiter. Propellant recharge, if required, is performed prior to entering the airlock. The MMU-to-PLSS latches are fail safe in that the crewmember can disengage from the unit if the latch on either side releases. Nominally the latches on both sides are released. (Although the MMU is designed to fit through the airlock latch, it is not intended that this will be part of the normal operational sequence.)

The sequence of tasks performed after MMU flight operations are complete is summarized below. The doffing sequence will require no more than 5 minutes (plus recharge, if required).

- Return to the FSS.
- Lock MMU to FSS.
- Power down MMU.
- Doff MMU

- Remove EVA support equipment from MMU.
- Recharge propellant tanks (see Section 5.4).
- Secure MMU for entry.

5.4 MMU Servicing

The MMU can be serviced by a single crewmember while it is mounted in the FSS. Spare batteries, stowed in the pressurized crew compartment, can replace used batteries in the MMU; battery replacement takes less than 5 minutes. Two fully charged batteries provide 540 watt hours of power; the nominal MMU load is 30 watts. (Battery recharge, if required, is accomplished in the pressurized airlock of the Orbiter using the EMU recharge system. Up to 16 hours are required to establish a full charge.)

Recharge of the MMU nitrogen propellant tanks can be performed at the FSS using a pressurized nitrogen supply (3,000 psi maximum) available from the Orbiter. A quick disconnect establishes the connection between the Orbiter supply and the MMU. Gages and toggle valves mounted on the MMU and the FSS are utilized to monitor and control repressurization (see Figure 24c). Propellant recharge of both tanks can be completed in less than 10 minutes.

Since the Orbiter supply (3,000 psi maximum) is less than the initial ground charge of the MMU (4,500 psi), the delta velocity available from the recharge will typically be 80 to 100 fps. A full ground charge provides 110 to 135 fps delta velocity capability.

6.0 CONSUMABLES PARAMETRICS

6.1 Propellant Consumption Parametrics

The rate at which MMU propellant is consumed is dependent on a number of related factors which will vary for each specific case. In addition, the crewmember utilizing the MMU can affect propellant consumption to a large degree by the manner (velocities, trajectories, etc) in which maneuvers are accomplished. Several guidelines can be used to estimate GN_2 usage for typical MMU orbital operations. Tables 2 and 3, and Figures 25 through 27, present various propellant consumption parametrics which should enable potential users to estimate MMU propellant utilization for specific applications.

The ground rules established to generate these parametrics are based on a specific set of MMU characteristics, system performance criteria, and simplifying assumptions. Although individual performance parameters would vary somewhat if a different--and equally pertinent--set of ground rules were used, the data in the tables represent reasonable guidelines to judge task requirements. Factors which could affect the calculations include system mass (crewmember mass, propellant mass remaining), center of mass offsets, applied torques, cargo mass, and changing propellant I_{sp}. For the purposes of constructing the tables, the system weight is assumed to be 620 lb (282 kg, 95th percentile male astronaut/EMU/MMU total) and is assumed to remain constant (propellant mass change is neglected). The propellant tanks are assumed to be fully charged (40 lbs of GN_2 at 4,500 psia and 70°F). Since the MMU control logic is designed to compensate for cm offsets and the resulting constant torques by turning off thrusters intermittently in the attitude hold mode during translational commands, such factors are assumed to have negligible effect on propellant consumption (as is illustrated in Table 3). Effects of temperature changes on propellant specific impulse (I_{sp}) are also neglected in these examples. Specific examples of the effects of cargo mass and applied torques are illustrated in the tables and figures.

Table 2 lists MMU travel times and fuel usage for various distances at typical velocities. Cargo weights are over and above EMU/MMU system weight of 620 lbs. Four thrusters are utilized (in ±X axis), and provide 1.4 lbs of thrust each. Nominal travel (coast) velocities are typically 1% (in feet per second) of the initial separation distance (feet); i.e., 3 fps for 300-foot travel.

Table 3 illustrates the effects on fuel consumption and travel times when MMU translations are performed in automatic attitude hold with an offset in system center of gravity due to a relatively large cargo mass. Essentially, these offsets do not result in significantly increased fuel consumption, but merely increase slightly the amount of time needed for translation. The MMU control logic turns 2 of 4 thrusters off periodically during translational acceleration to counteract the torque present due to the c.g. offset.

Figure 25 shows fuel consumption as a function of total equivalent delta velocity in translation. Total ΔV for any maneuver is twice the coast velocity achieved (i.e., fuel is used for acceleration and braking), and is additive for all such maneuvers during a mission.

Figures 26 and 27 depict MMU travel times as a function of distance for various coast velocities. The t_{min} curve shows travel times for various distances when no coasting is done; i.e., MMU accelerates for half the separation distance, decelerates for the other half. This would not, it should be noted, be the normal method for translation.

Figure 28 shows fuel consumption as a function of distance when coast velocity equals 1% (in feet per second) of the initial separation distance (feet). This is the nominal velocity which will be achieved to translate over various distances of 100 feet or more, based on anticipated comfortable coast velocities utilizing visual cues.

Table 2 MMU Travel Times (One Way) and Propellant Usage Versus Distance and Cargo Weight

Distance One Way (feet)	Cargo Weight (lb)	Velocity Attained (fps)	Total Time (sec)	Coast Time (sec)	Percent Fuel Consumed
300	0	9.5 (max)	63	0	14.0
300	0	5	77	43	7.4
300	0	3 (Nominal)	110	90	4.5
300	0	2	158	144	3.0
300	100	8.8 (max)	68	0	15.0
300	100	5	79	41	8.6
300	100	3 (Nominal)	112	89	5.2
300	250	8.03 (max)	75	0	16.8
300	250	3 (Nominal)	114	86	6.2
200	0	7.7 (max)	52	0	11.4
200	0	5	57	23	7.4
200	0	2 (Nominal)	107	94	3.0
200	100	7.2 (max)	56	0	12.4
200	100	5	59	21	8.6
200	100	2 (Nominal)	108	92	3.4
100	0	5.4 (max)	36	0	8.0
100	0	5	37	3	7.4
100	0	1 (Nominal)	103	97	1.5
100	100	5.1 (max)	39	0	8.8
100	100	1 (Nominal)	104	96	1.7

NOTES:

1) Does not include attitude hold propellant usage (negligible in most cases).
2) Assumes constant I_{sp} (= 60), constant system mass.
3) Calculated for 95% man, total weight (man/EMU/MMU) = 620 lbs (282 Kg).
4) Acceleration $\propto$ system mass.
5) Propellant mass used = $C\Delta V$, where $C \propto$ system mass
6) Maximum velocity attained is that achieved when half the travel distance is used for acceleration, half for deceleration--with no coast time. Nominal velocity is the anticipated comfortable coast velocity which the crewmember will probably utilize.
7) Total usable propellant is 40 lbs.

Table 3 Translation in Automatic Attitude Hold with CG Offset

- Crewmember carries 250 lb mass whose center of gravity is 1.5 ft below MMU/EMU cg.
- The total system (MMU/EMU + cargo) cg is therefore offset by 0.43 ft in Z axis.
- MMU logic compensates for this offset by periodically turning off two X-axis thrusters during translational acceleration. This increases the time required to achieve a given velocity as shown below.

	Translation Distance (ft)	Cargo Weight (lb)	V_{max} (fps)	Time(sec) to Achieve 3 fps	Coast Time (sec)	Total Time (sec)	Percent Fuel Consumed
No AAH, No CG Offset	300	250	3.0	14	86	114	6.23
AAH, with .43 ft CG Offset in Z	300	250	3.0	16	84	116	6.24

- Essentially, cg offsets do not result in increased fuel consumption, but merely increase slightly the amount of time needed for translation.

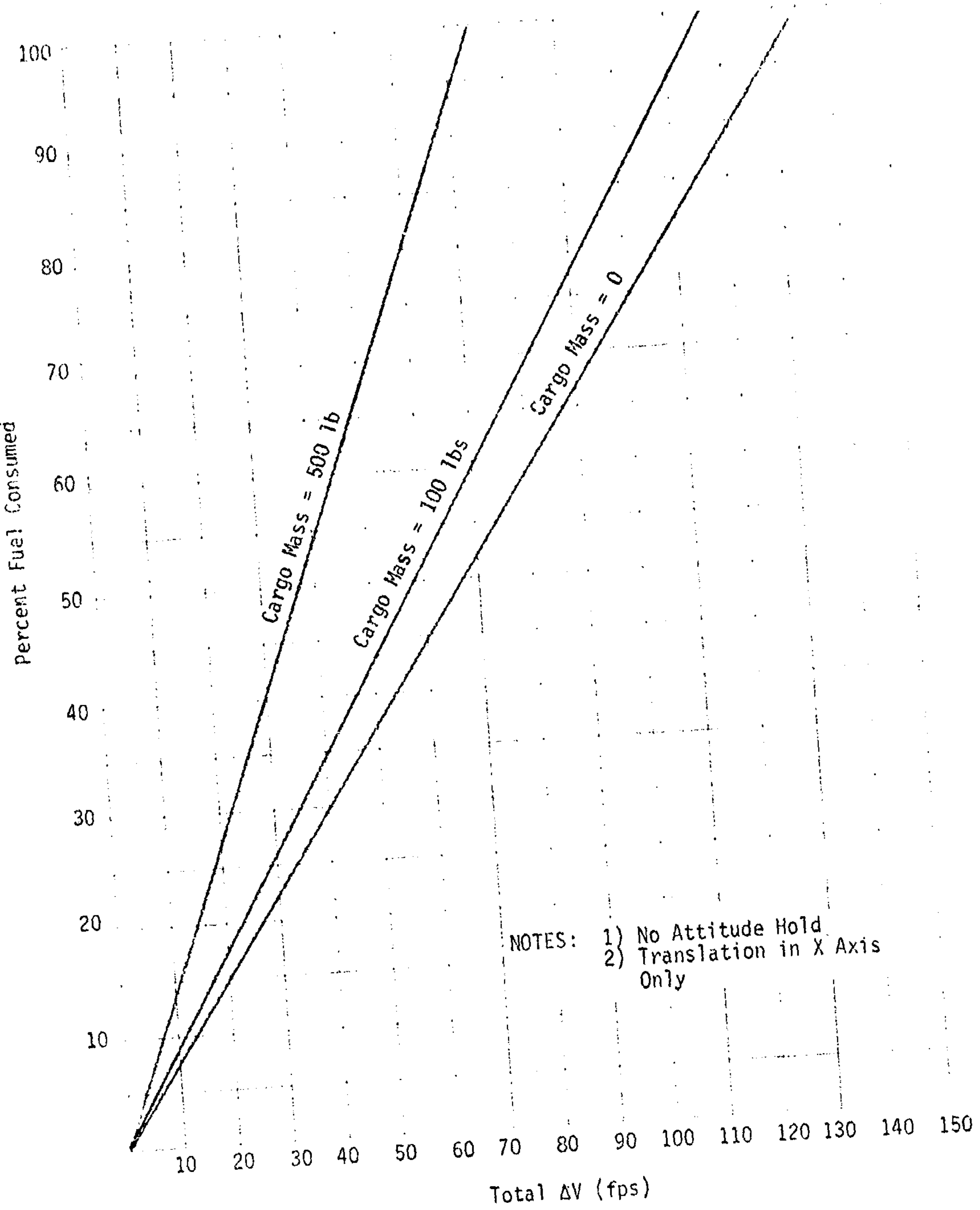


Figure 15 Percent Fuel Consumed vs Total ΔV

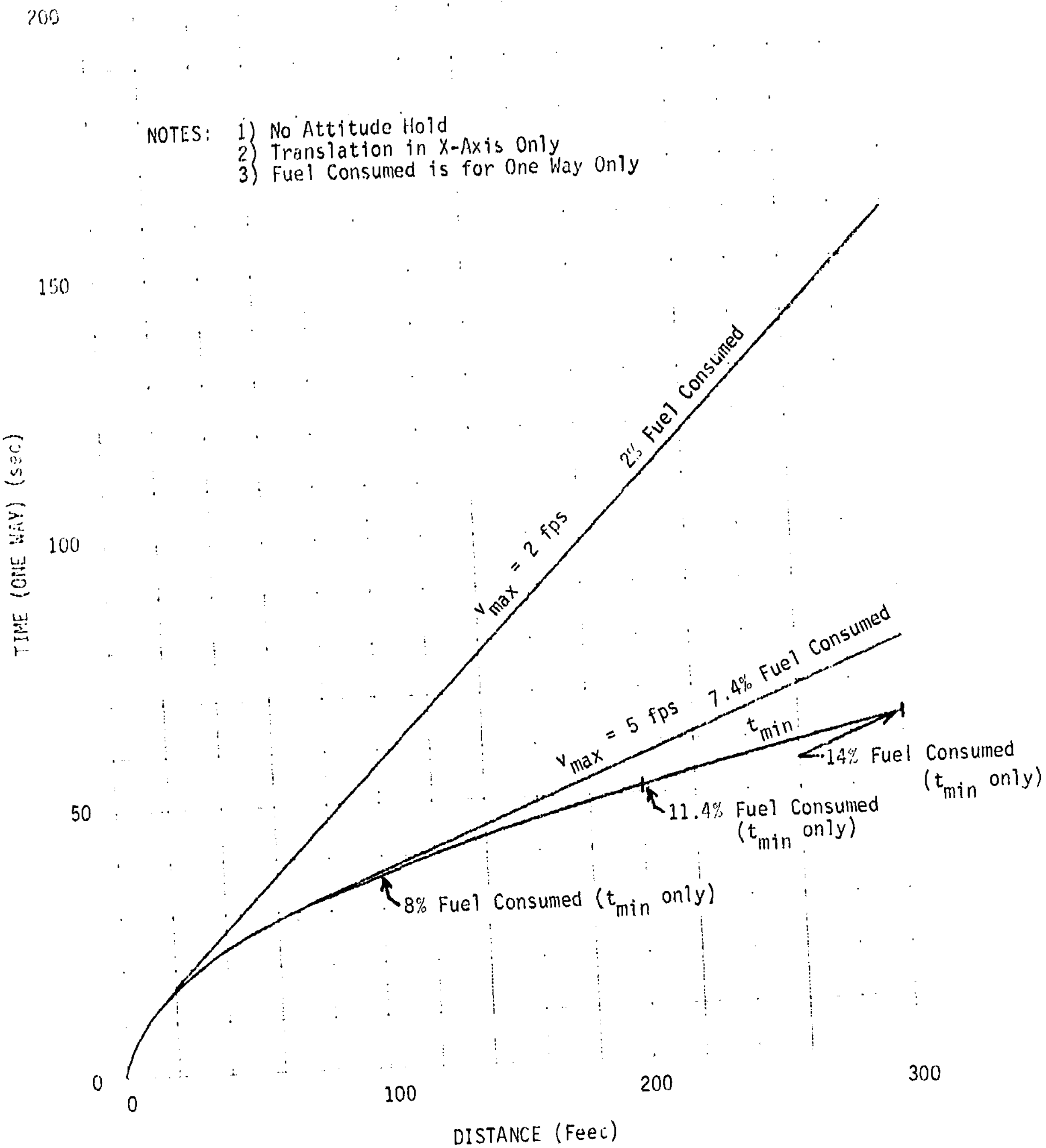


Figure 26 MMU Travel Time versus Distance (Cargo Weight = 0)

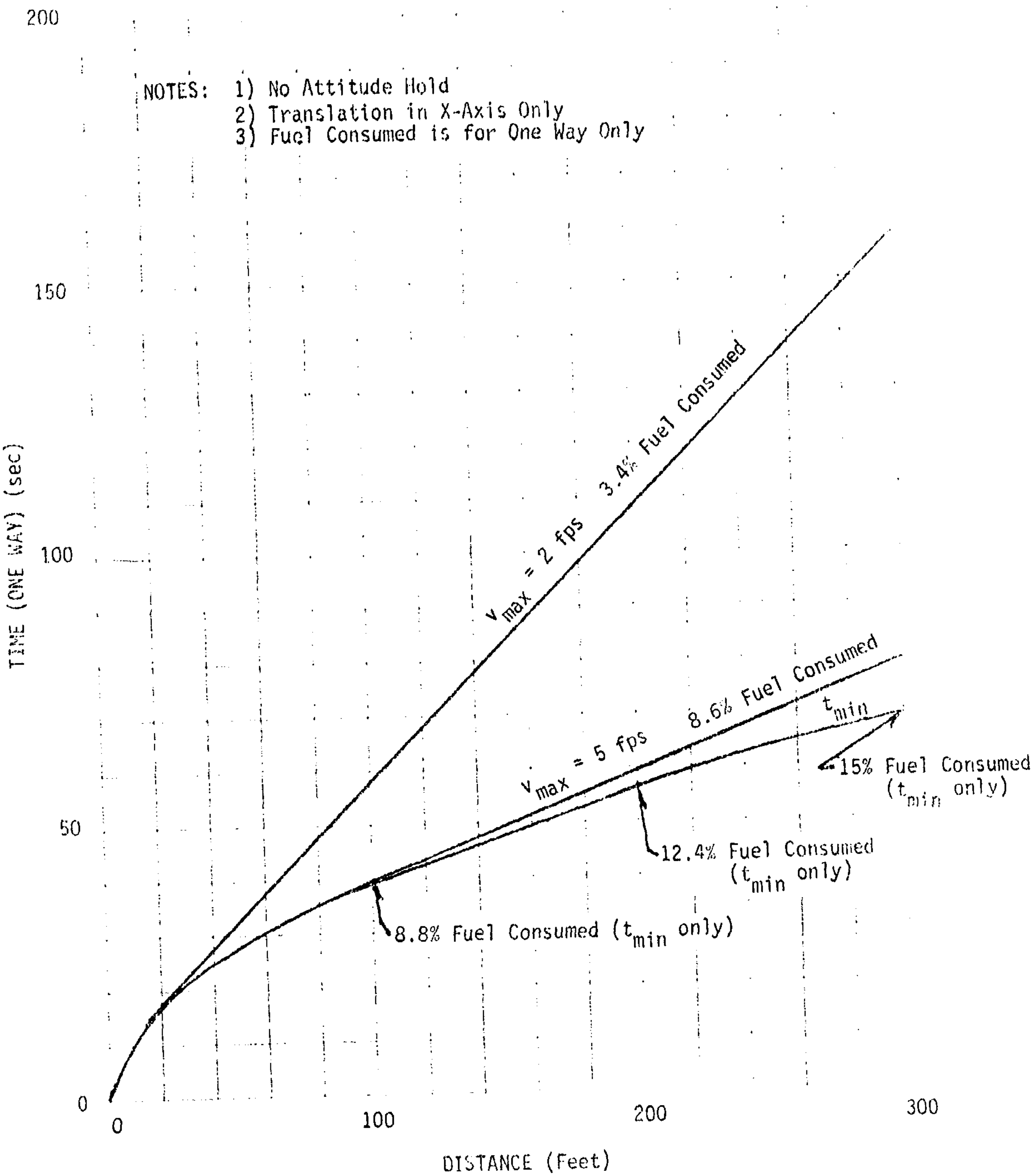


Figure 27 MMU Travel Time versus Distance (Cargo Weight = 200 lbs)

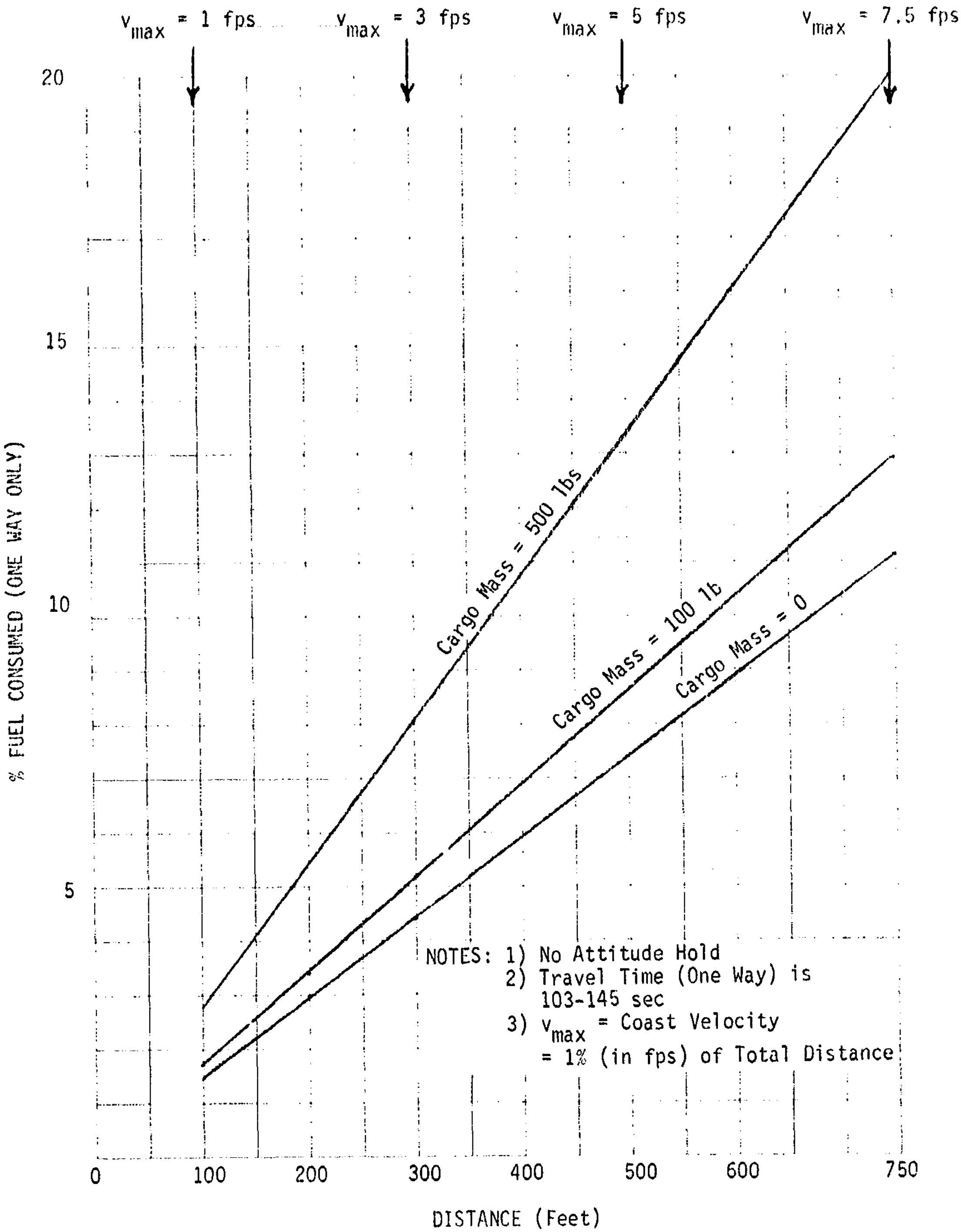


Figure 28 Percent Fuel Consumed vs Distance (v_{max} = 1% Total Distance)

6.2 Power Consumption Parametrics

The MMU typically consumes an average of 30 watts, assuming the rate gyros are on constantly. Since the MMU includes floodlights to illuminate a work area and power outlets to operate ancillary equipment or tools, this typical load could increase dramatically during orbital operations. Table 4 presents MMU power consumption parametrics for typical orbital operations. It should be noted that the rate gyros would normally be turned off when the MMU is at a work site and that, since thrusters would not normally be firing during this period, significant power can be saved below the nominal 30 watt maximum. Thus, the MMU would typically consume much less than the 180 watt-hours shown in Table 4, and this power saved would be available to operate ancillary equipment. The 540 watt-hours shown available for orbital operation is, therefore, a worst-case estimate.

Table 4 MMU Power Consumption Parametrics

• Battery Capacity (full charge, both batteries)	720 watt-hours
• Average Maximum MMU Operational Load, 30 watts x 6 hour mission	- 180 watt-hours
• Power available for orbital operations support:	540 watt-hours
- Floodlights (2) - 25 watts total	
- Power outlets (2) - 28V DC @ 2 amp max each	
• Typical mission - 6 hour duration	
- 2 floodlights operational @ worksite for 5 hrs	125 watt-hours
- camera operational @ 0.5 amp for 2 hours	28 watt-hours
- 1 power tool operational @ 1.5 amp for 5 hours	210 watt-hours
Margin = 177 watt-hours (batteries recharged/replaced prior to next EVA)	363 watt-hours
• Typical mission - 6 hour duration	
- 2 floodlights operational @ worksite for 1 hour	50 watt-hours
- ancillary equipment operational @ 0.5 amp for 3 hours	42 watt-hours
Margin = 448 watt-hours (no battery recharge required prior to next EVA)	92 watt-hours

6.3 Application to Typical MMU Scenarios

The following four examples illustrate typical scenarios and missions which an MMU-equipped crewmember could perform. Estimates of fuel consumption in each case are given for the individual steps of each task.

Example 1 - Orbiter MMU Mission Example Outline - This mission example is not intended to be representative of any specific current task but rather was designed to exercise a complex series of maneuvers believed to be typical of near-Orbiter operations.

The design reference Orbiter MMU mission outlined here involves an inspection of the total Orbiter exterior for any number of candidate reasons (entry status assessment, retrieval of data samples, or photographic documentation of the Orbiter exterior). Table 5 contains a sequenced description of the tasks/operations, equipment required, and estimated time requirements for each task. One crewmember (CM1) performs the EVA/MMU tasks with a second EVA crewmember (CM2) observing from the payload bay. Two crewmembers are not required to complete the task.

Translation Route and Travel Distance - A typical MMU translation route is shown in Figures 29 and 30. This route encompasses inspection of critical reentry and subsystem areas plus activity at a fixed location, if required, aft of the Orbiter main landing gear (right side). Table 6 shows the estimated travel distance for each major leg of the mission and includes an estimated number of direction changes.

Total Delta V Required - The translation ΔV required for the MMU checkout, Orbiter inspection, and task objectives is approximately 30 ft/sec (9 m/sec). From M509 on-orbit experience, it was found that the ΔV used for rotation is approximately equal to that required for translation. Therefore, the total ΔV for both translation and rotation is approximately 60 ft/sec (18 m/sec).

Table 5 Typical MMU Mission Description

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	ESTIMATED TIME (min.)
<u>Prep and Checkout</u>				
Egress airlock	X	X		2.0
Prep equipment and don MMU	X	X	Portable lights, tethers, camera	16.0
MMU checkout and familiarization flight in payload bay	X			6.0
			Time Subtotal	24.0
<u>Inspection Task</u>				
Egress payload bay	X			1.0
Inspect Orbiter (including TPS tiles, doors, control surfaces, engines, etc)	X		Lights, camera	92.0
Ingress payload bay	X			2.0
			Time Subtotal	95.0
<u>Repair or Collection of Samples</u>				
Set up EVA support kit and associated hardware	X	X	Portable workstation	10.0
Egress payload bay	X			1.0
Repair malfunction or collect samples	X		Support kit--portable workstation, lights camera	52.0
Ingress payload bay	X			2.0
Doff/stow MMU and equipment	X	X		10.0
Ingress airlock	X	X		2.0
			Time Subtotal	77.0
			TIME TOTAL	196.0

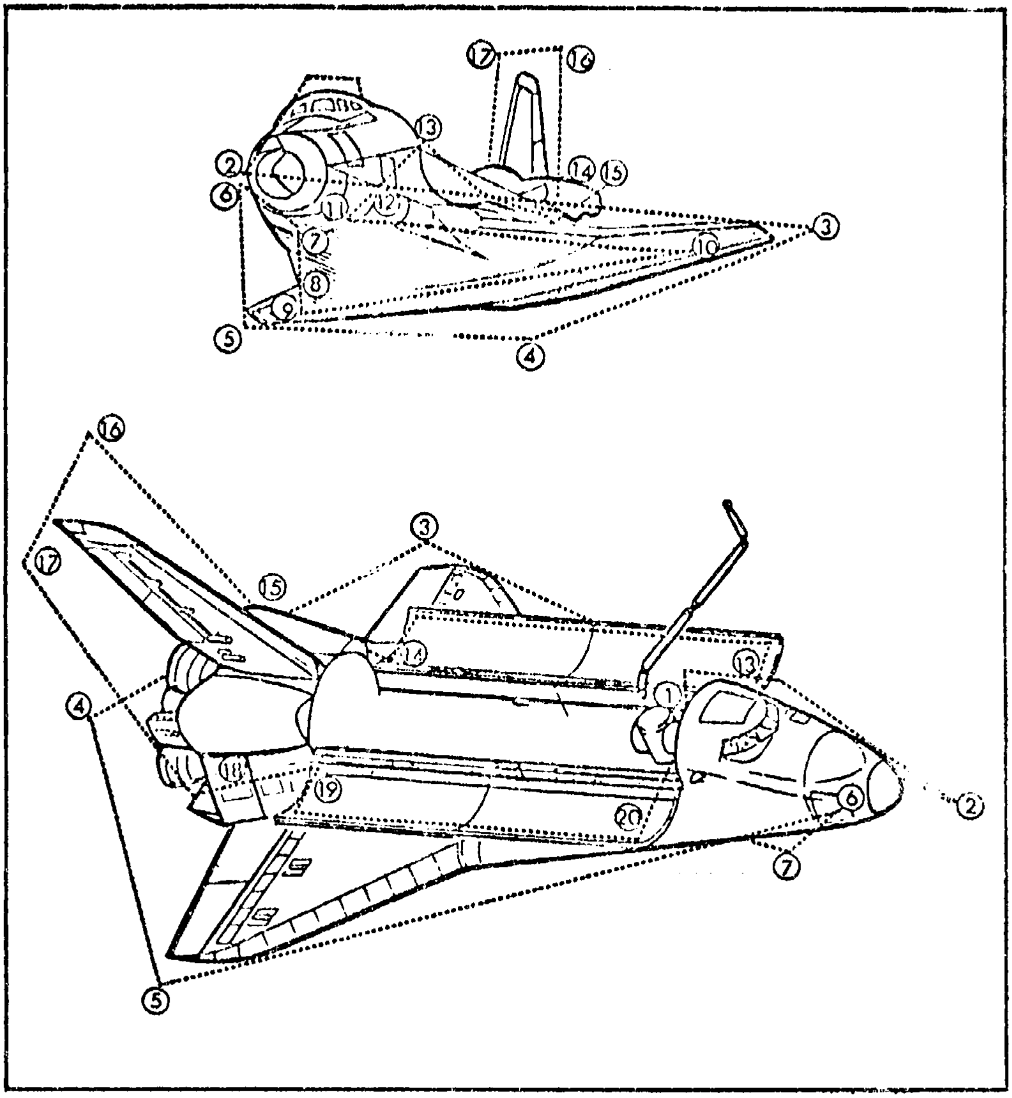


Figure 29 Typical Orbiter Exterior Inspection Route using MMU

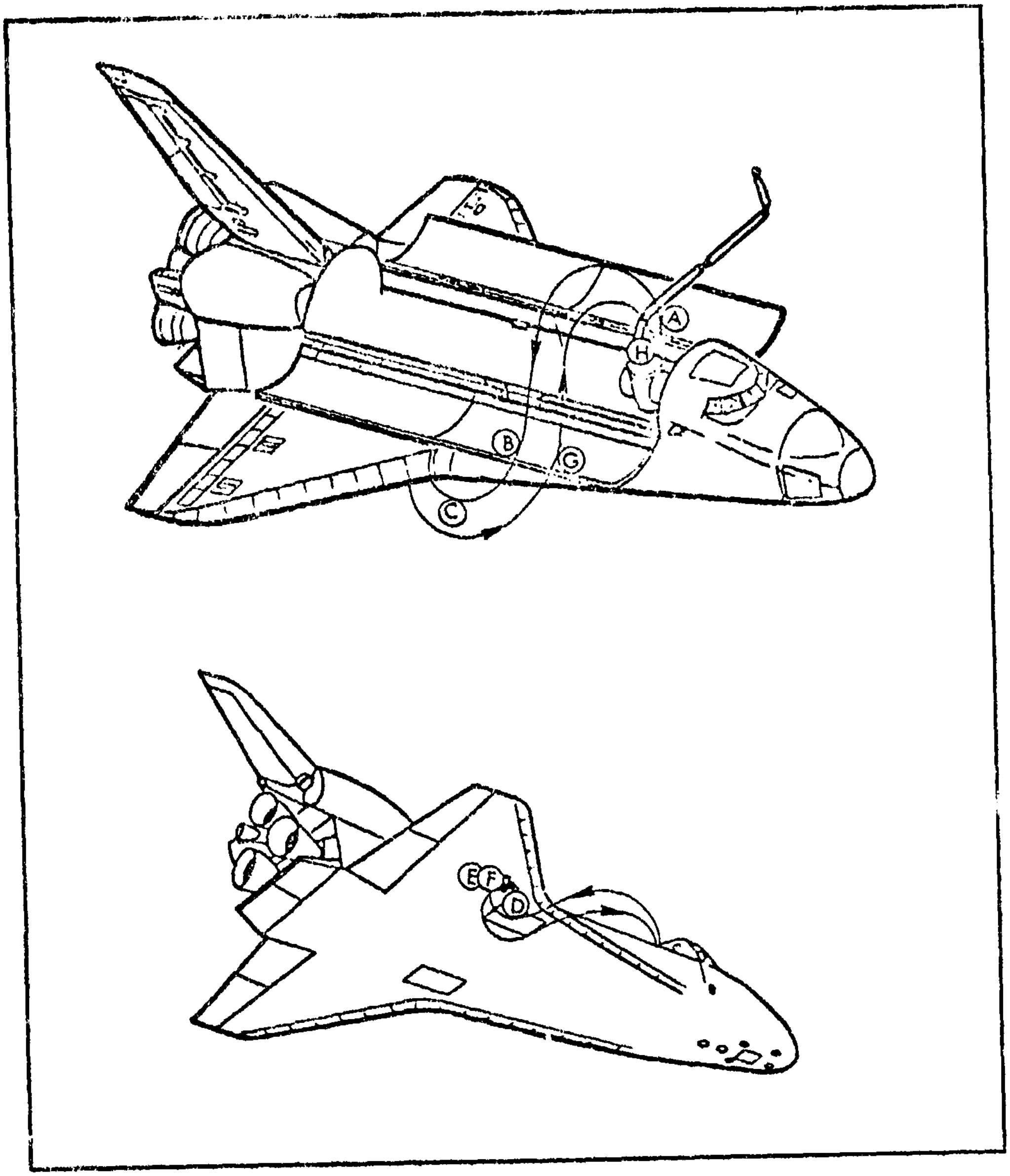


Figure 30 MMU Translation Route for Activities at a Fixed Worksite Identified during the Inspection Phase

Table 6 Estimated Distance and Direction Change

TRAVEL DISTANCE			DIRECTION CHANGE 3-axes (degrees)			TRANSLATION LINEAR CHANGE	VELOCITY		DELTA V TRANSLATION	
	m	ft	roll	pitch	yaw	starts/stops	m/sec	ft/sec	m/sec	ft/sec
CHECKOUT	40.0	150	360	360	360	14	0.09	0.3	1.26	4.2
INSPECTION TASK										
1 to 2: Over cabin forward of nose and stop	22.9	75		30	360	4	0.12	0.4	0.48	1.6
2 to 3: Around left side at wing level	36.6	120		15	45	2	0.15	0.5	0.30	1.0
3 to 4: Left wing tip to center line aft of main engines	18.3	60		10	60	2	0.15	0.5	0.30	1.0
4 to 5: Aft centerline to right wing tip	18.3	60			30	2	0.15	0.5	0.30	1.0
5 to 6: Right wing to right RCS door	33.5	110		10	45	2	0.15	0.5	0.30	1.0
6 to 7: RCS downward to underside	6.1	20		30	15	4	0.09	0.3	0.36	1.2
7 to 8: Forward underside to aft	21.3		20			4	0.15	0.5	0.60	2.0
8 to 9: Right landing gear door to flag symbol on wing	6.1	20		10		2	0.09	0.3	0.18	0.6
9 to 10: Flag to left wing USA symbol (stop at center line)	13.7	45	90			2	0.15	0.5	0.3	1.0
10 to 11: Left wing to nose wheel door	21.3	70	90			2	0.12	0.4	0.24	0.8
11 to 12: Nose wheel to glove fairing (left wing)	7.6	25		30	15	4	0.09	0.3	0.36	1.2

Table 6 (Continued)

TRAVEL DISTANCE			DIRECTION CHANGE 3-axes (degrees)			TRANSLATION LINEAR CHANGE	VELOCITY		DELTA V TRANSLATION	
	m	ft	roll	pitch	yaw	starts/ stops	m/sec	ft/sec	m/sec	ft/sec
12 to 13: Glove fairing to P/L door	9.1	30		60	90	2	0.09	0.3	0.18	0.6
13 to 14: Along P/L door	24.4	80			90	4	0.09	0.3	0.36	1.2
14 to 15: Along aft left RCS shroud	7.5	25	180	60		4	0.09	0.3	0.36	1.2
15 to 16: RCS shroud to top of vertical stabilizer	15.2	50				2	0.09	0.3	0.18	0.6
16 to 17: Across vertical stabilizer	7.6	25	180	30		2	0.09	0.3	0.18	0.6
17 to 18: Top vertical stabilizer to right RCS shroud	15.2	50		30		2	0.15	0.5	0.3	1.0
18 to 19: Right RCS shroud to right P/L door	7.6	25		90		4	0.09	0.3	0.36	1.2
19 to 20: Along right P/L door	24.4	80			180	4	0.09	0.3	0.36	1.2
20 to 21: Right P/L door into P/L bay	6.1	20	90	90	180	4	0.09	0.3	0.36	1.2
Subtotal	368.9	1210	1010	855	1470	72	N/A	N/A	7.62	25.4
<u>REPAIR OR COLLECTION OF SAMPLE</u>										
A to B: P/L bay MMU stowage to right side P/L door	18.3	60				2	0.18	0.6	0.36	1.2
B to C: Right P/L door downward to underside of Orbiter	4.6	15				2	0.12	0.4	0.24	0.8

Table 6 (Concluded)

TRAVEL DISTANCE				DIRECTION CHANGE 3-axes (degrees)			TRANSLATION LINEAR CHANGE	VELOCITY		DELTA V TRANSLATION	
		m	ft	roll	pitch	yaw	starts/ stops	m/sec	ft/sec	m/sec	ft/sec
C to D:	Underside to worksite area near right side landing gear door	9.1	30		90	90	2	0.15	0.5	0.3	1.0
D to E:	Workstation placement and ingress at worksite			60	10	5	4				
E to F:	Workstation egress and removal at worksite			60	10	5	4				
F to G:	Worksite area to P/L bay door	13.7	45				2	0.18	0.6	0.36	1.2
G to H:	P/L bay door to P/L bay stowage area	18.3	60		90	270	2	0.18	0.6	0.36	1.2
	TOTALS	432.7	1420	1130	1055	1840	90	N/A	N/A	9.24	30.8
Rotational Delta V (equivalent) = 30.8 ft/sec											
Total Delta V = 61.6 ft/sec											
Total Fuel Consumed = 46%											

Example 2 - LDEF Stabilization - The payload MMU design reference mission outlined in this section utilizes the MMU/EVA crewmember to supplement retrieval of a payload.

The payload featured is the retrieval of the Long Duration Exposure Facility (LDEF) utilizing the remote manipulator system (RMS). The MMU is used to provide stabilization of the LDEF while the Orbiter approaches, to ensure the satellite will be in a stable mode for the RMS retrieval.

Operations - Moments of inertia used were LDEF I_y = 57,400 slugs-ft^2, MMU 58.5 slugs-ft^2. LDEF dimensions used were 14 ft diameter by 30 ft long. See Figure 31. Disturbing angular impulses arising from interaction with the Orbiter equivalent to that required to impart a spin rate of 2 degrees per second to the LDEF about its principal axis, yielding the maximum moment of inertia, were assumed.

Summary - Table 7 provides a summary of the MMU operations for accomplishing LDEF retrieval. The ΔV capability required for this support operation based on the listed initial conditions was 44 ft/sec for translation and attitude control.

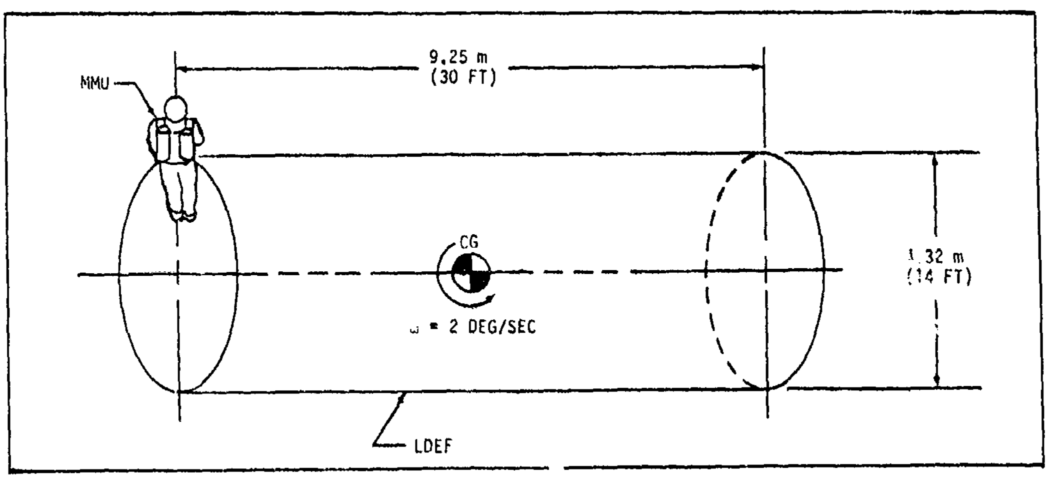


Figure 31 LDEF Stabilization

Table 7 LDEF Stabilization

Orbiter closes to stationkeeping position approximately 100 yards out for contamination prevention. LDEF is a passive, gravity gradient stabilized payload. It will, in this example, have protective covers that will be installed by the crewmen and then be retrieved by the RMS with the MMU providing limited active stabilization to facilitate grappling.

	Distance (ft)	Rate (ft/sec)	ΔV (ft/sec)
1. MMU checkout (in bay)	-	-	4.0*
2. Fly to LDEF	300	3.0	6.0
3. Stationkeep at LDEF (photograph LDEF condition)	-	-	2.0*
4. Install/deploy protective covers as required	-	-	4.0
5. Dock to end of LDEF	-	-	2.0
6. Stabilize LDEF as Orbiter closes to RMS grapple range (MMU ΔV dequired to provide payload stabilization equivalent to 2°/sec in one axis)			9.0*
7. (RMS grapple) MMU undocks and stands off 50 ft	50	0.5	1.0
8. Stationkeep and photograph while payload is inserted in payload bay	-		1.0*
9. MMU returns to FSS and docks	50	0.5	1.0
Translation ΔV			30
Attitude control (ΔV equivalent)			14
Total equivalent ΔV			44 ft/sec

*Not included in attitude control ΔV. Fuel Consumed = 33%

Example 3 - Multiple Module Transfer - This example payload mission will use the MMU/EVA crewmember to perform a multimodule transfer. The modules are considered as high mass (600 lb) and will be transferred to a construction site 300 ft from the Orbiter.

Operations - Two EVA crewmembers are used for the module transfer from the Orbiter. One crewmember unstows the modules in the payload bay and the MMU/EVA crewmember transfers them to the construction site--300 ft --while the Orbiter stationkeeps. The same thrusting times were used for the loaded and unloaded crewmember to produce translation rates of 1.5 and 3.0 feet per second, respectively.

Summary - The example indicates that 64 feet per second of ΔV is required to accomplish the transfer of two 600-lb modules to the construction site 300 feet away. At least one additional module could be transferred before recharge of the system would be required. Table 8 provides a ΔV summary of the operations.

Table 8 Multiple Mass Transfer

	Distance (ft)	Rate (ft/sec)	Equiv. ΔV (ft/sec)
1. MMU checkout	-	-	4.0*
2. Transfer Module #1	300	1.5	6.0
3. Positioning of module at site	-	-	3.0*
4. Return to Orbiter	300	3.0	6.0
5. Transfer Module #2	300	1.5	6.0
6. Positioning of module at site	-	-	3.0*
7. Return to Orbiter	300	3.0	6.0
Translation ΔV			24
Attitude Control (no translation)			10
Attitude control (during unloaded translation, equal to translation ΔV)			12
Attitude control (during loaded translation, equal to translation ΔV plus 50% due to more propellant required because of offset c.g.)			18
Total ΔV equivalent required			64 ft/sec
*Not included in attitude control ΔV.		Total Fuel Consumed = 47%	

Example 4 - Five-Hour Work Site Task - Table 9 presents a typical scenario to illustrate the relative amounts of fuel that could be consumed during a 5-hour EVA with the MMU. The scenario depicted is described by the following steps:

- Crewmember translates 100 m (300 ft) to work site at maximum velocity of 3 fps, and stays at site for 5 hours.
- During those 5 hours, the crewmember translates 20 m (60 ft) in ±Y axis (at coast velocity of 2 fps) every 20 minutes.
- During the 20 minutes at each end of the work site, the crew member is in automatic attitude hold mode. During that time disturbance torques are present in two forms--an umbilical torque of 0.11 ft-lb in two axes and limb motion torques in two axes which cause the MMU to drift out of the AAH deadband. Both these torques are applied once every minute for 5 seconds each time--during the entire 5 hour work period.

Table 9 Fuel Consumed During 5-Hour EVA Task

Maneuver	Δ Velocity/Time	% Fuel Consumed
300 m Translation to Work Site	6 fps/110 sec	4.5
20 m Translation - 15 times in 5 hours	4.0 fps/37 sec	44.4
Overcoming umbilical torque	8.3% duty cycle (5 sec/60 sec) 2 axes	16.7
Overcoming limb motion torques	8.3% duty cycle (5 sec/60 sec) 2 axes	7.2
300 m translation from work site	6 fps/110 sec	4.5
TOTAL		77.3% (30.9 lb GN_2)

This scenario is in some respects a worst case example because disturbance torques of the types described would rarely be present at the rates or for the lengths of time indicated. It should also be noted that the Y axis translation velocities are three times higher than the nominal 1% ground rule (described in Table 2 and Figure 26). It was assumed in this case that the crewmember would use these higher translation velocities during extended EVA periods at the work site in order to proceed as quickly as possible to each end of the site. Thus it is assumed that the work site is familiar to the crewmember and that higher velocities in the $\pm$Y axis are still comfortable. (NOTE: Lower velocities would consume less fuel.)

APPENDIX A - MMU TECHNICAL DESCRIPTION

A.1 Hardware Design

The principal elements of the Manned Maneuvering Unit are its basic structure, a propulsion subsystem, two hand controllers, and a control electronics assembly (CEA). Figure A-1 shows a block diagram of the MMU, and Figures A-2, A-3, and A-4 illustrate the principal components. Twenty-four fixed-position thrusters utilizing gaseous nitrogen (GN_2) provide full six-degree-of-freedom control by reacting to commands from the three-axis translational hand controller (THC) and the three-axis rotational hand controller (RHC). Electrical power is supplied to the MMU subsystems from two batteries mounted at the top rear of the unit between the GN_2 pressure vessels. Command logic, power conditioning equipment, and gyroscopes are mounted in the control electronics assembly (CEA) located behind and below the batteries.

The MMU is a fail-safe system in that any single failure does not preclude the astronaut from returning safely to the Orbiter vehicle. The thrusters are separated into two independent systems (12 thrusters each), each of which provides full six-degree-of-freedom control in the event of a failure in the other system. The control electronics are also redundant such that at least one set of twelve thrusters can always be commanded.

In addition to the manual commands which are applied by the astronaut from the hand controllers, an automatic attitude hold (AAH) capability is also available. By activating a switch located on top of the RHC grip, the astronaut can command attitude hold and the MMU will maintain attitude in three axes of rotation by firing thrusters automatically, as required. Three rate gyros sense rotations and attitudes in each rotational axis, and the MMU control logic uses these data to command the thrusters. If rotational rates are already present when attitude hold is commanded, the control logic will fire thrusters to cancel those rates.

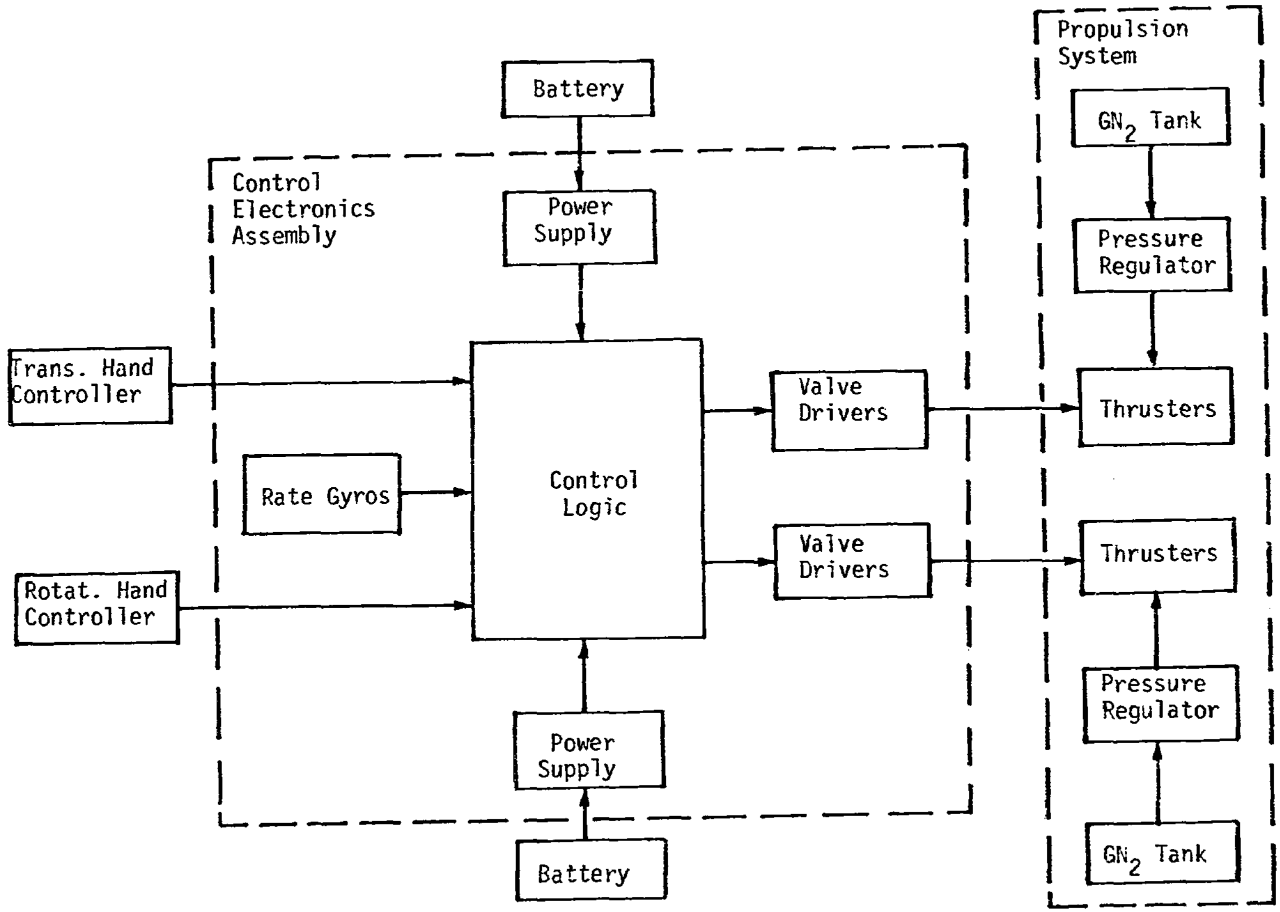


Figure A-1 MMU Functional Diagram

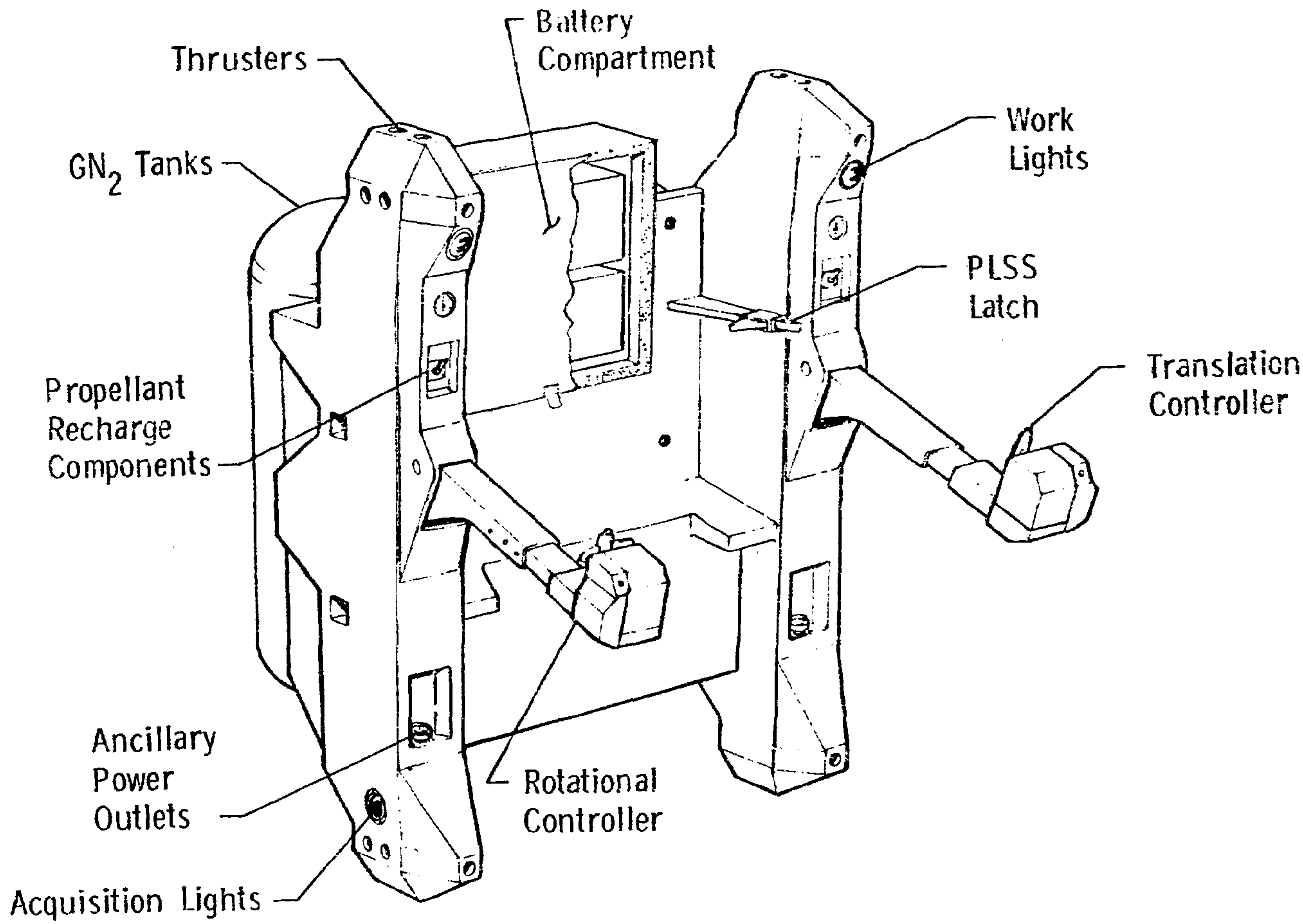


Figure A-2 Manned Maneuvering Unit

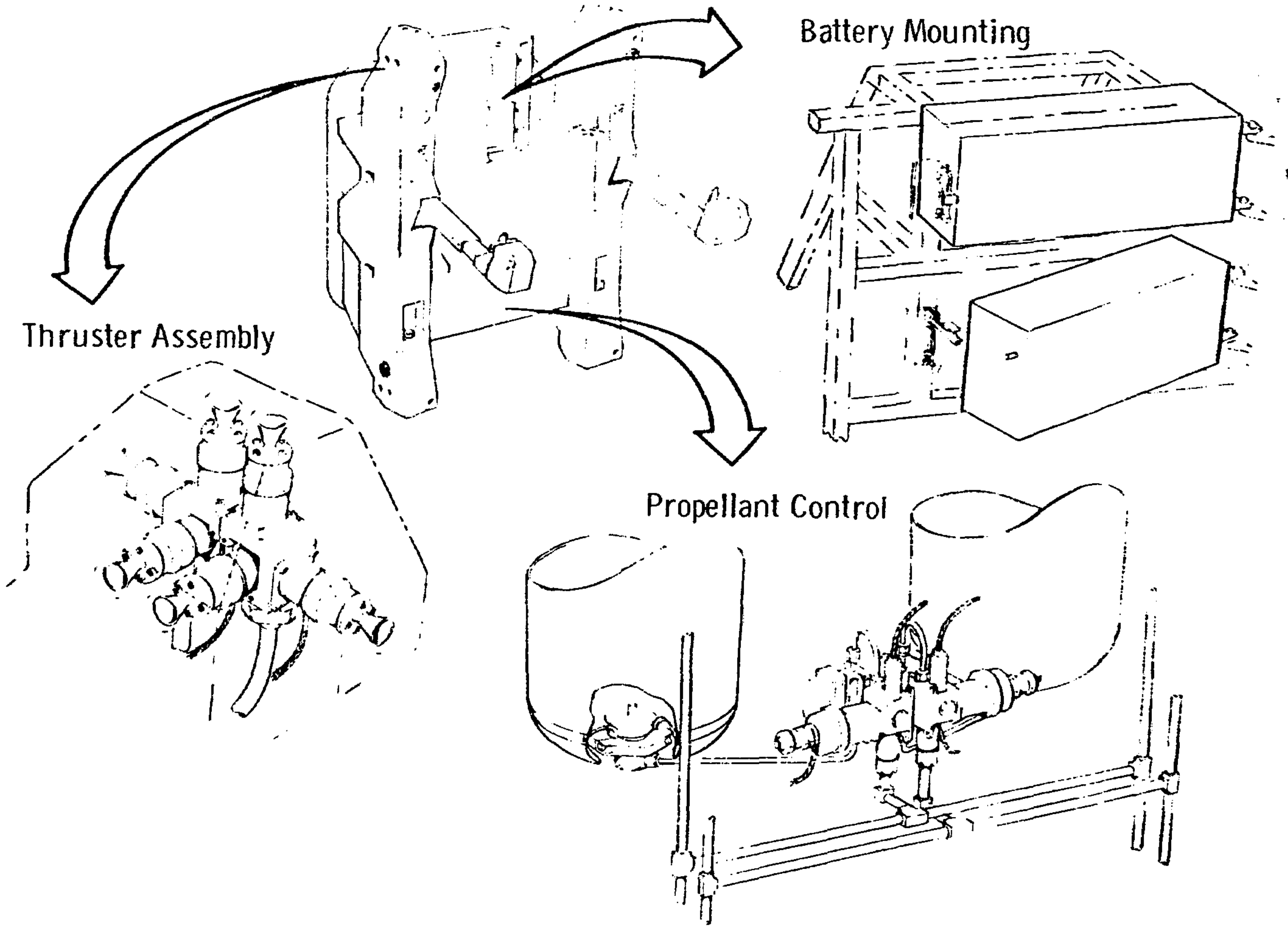


Figure A-3 MMU Major Subsystems (1 of 2)

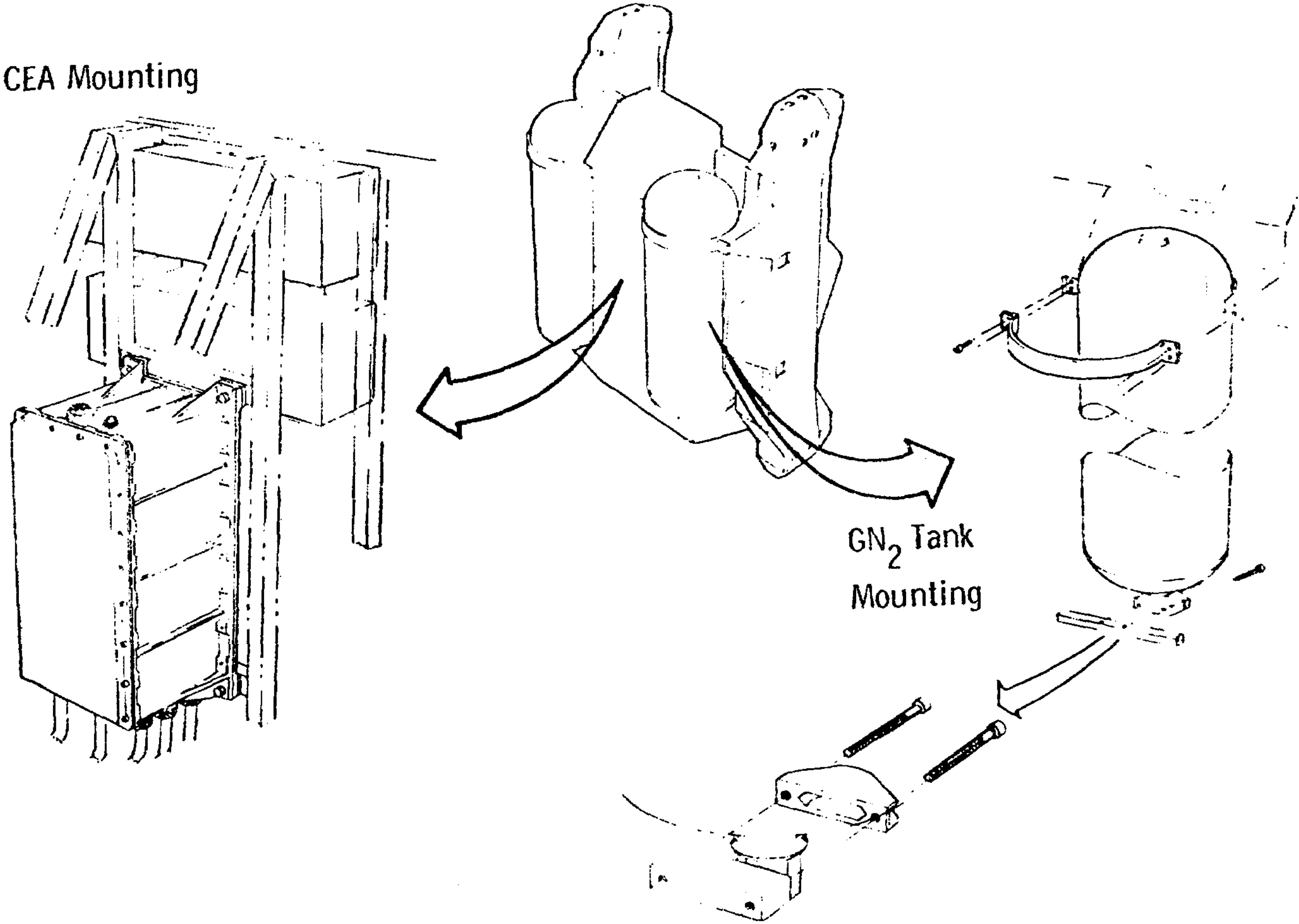


Figure A-4 MMU Major Subsystems (2 of 2)

The two propellant tanks contain a total of 40 lb (18 kg) of GN_2 at 4500 psia and 70°F, on initial charge on the ground prior to a mission. These pressure vessels are rechargeable during EVA by an unassisted crew member (see Section 5.3). The initial charge provides sufficient propellant for an equivalent ΔV of 110 to 135 fps; subsequent recharges on-orbit will provide a minimum equivalent ΔV of 72 fps (36 fps per GN_2 tank). The control logic of the MMU is designed to maintain fuel consumption from each tank at a relatively even level. In addition, the logic is designed to select the optimum combination of thrusters in order to conserve propellant when mass offsets are present or multiple axis commands occur simultaneously.

The MMU is stowed for launch and reentry in the Flight Support Station (FSS) located in the payload bay of the Orbiter (see Figure A-5). The FSS structure provides environmental protection to the MMU during launch, on-orbit (nonoperational) periods, reentry and landing. The FSS also contains the necessary attachment provisions, foot restraints and handholds for donning/doffing and servicing the MMU in orbit by an unassisted EVA crewmember. One FSS can be mounted on each side of the payload bay so two MMUs can be carried on each Orbiter flight.

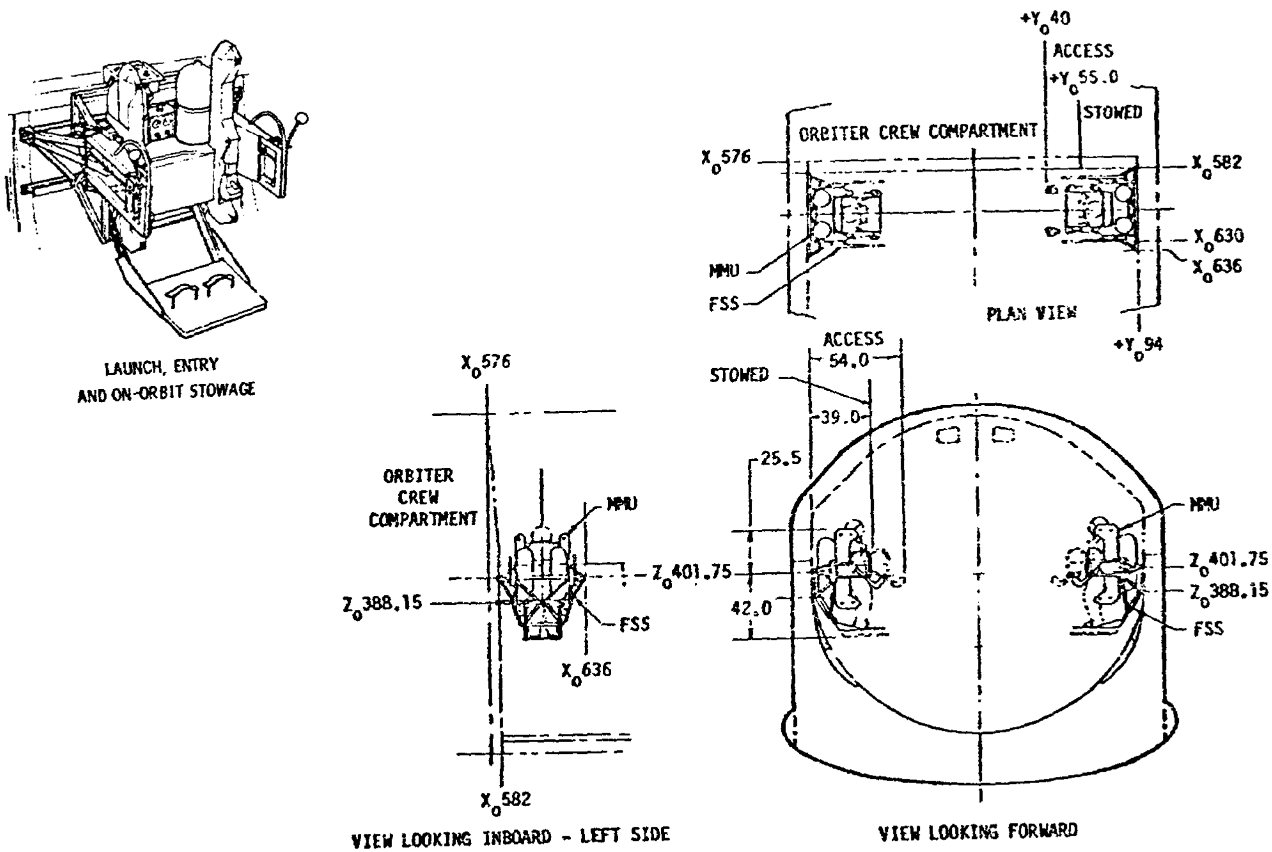


Figure A-5 MMU/FSS Configuration in Payload Bay

A.2 MMU Mass Properties

The total weight of the MMU is approximately 243 lb (110 kg), including a full charge of propellant (40 lb GN_2). Figure A-6 depicts the reference coordinate axis and shows the location of the center of mass of the EMU/MMU system. The maneuvering unit will accommodate personnel within the range of the 5th percentile based on anthropometric data for 1968 USAF women officers, to the 95th percentile based on data for 1980 male flying officers.

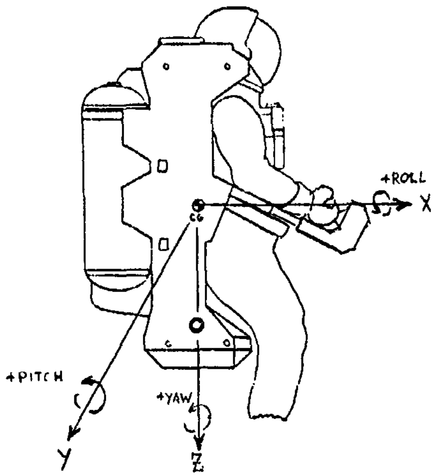
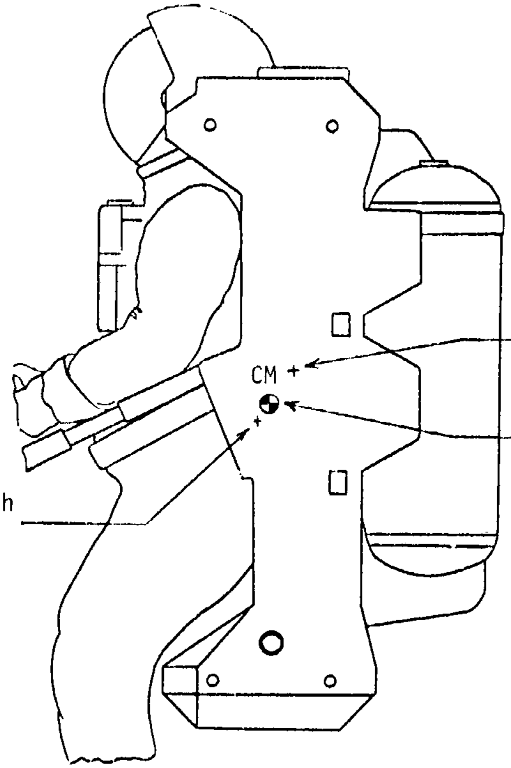


Figure A-6 MMU Reference Coordinate System

For each MMU carried aboard the Orbiter, a Flight Support Station (FSS) is required. The FSS is a structure to which the MMU is attached for launch and reentry of the Orbiter (see Section A.1). The weight of the FSS is approximately 50 lb (23 kg); hence the payload launch weight penalty for one MMU is approximately 293 lb (133 kg). It should be noted that the weight of the flight operational MMU system includes the astronaut and the extravehicular mobility unit (EMU). The astronaut weight can vary between 100 and 215 lb (45 to 100 kg); the EMU weight is approximately 175 lb (80 kg). Figure A-7 shows the location of the center of mass for typical astronaut/EMU/MMU systems. The MMU control system is designed to compensate for these cm offsets.

A.3 MMU Flight Characteristics

The maneuvering unit responds to direct manual commands input by the crewmember via the two hand controllers. For a nominal system mass,



EMU/MMU 5th Percentile Woman:

- Total mass = 504 lb (229 kg)

EMU/MMU 95th Percentile Man:

- Total mass = 640 lb (291 kg)

- Launch weight penalties:

MMU	243 lb (110 kg)
FSS	50 (23)
	293 lb (133 kg)

Figure A-7 Typical Centers of Mass for EMU/MMU System translation accelerations are 0.3 $\pm$0.05 ft/sec^2 and rotational accelerations are 10.0 $\pm$3.0 deg/sec^2. Since the MMU operates in a direct flight mode, these acceleration levels are present whenever either hand controller grip is displaced from the center or null position. Acceleration commands are terminated when the grip is returned to the center position. Simultaneous commands in several axes (multi-axis commands) are possible at reduced acceleration levels.

Each MMU thruster develops approximately 1.4 lbs of thrust; therefore single axis translation commands generate 5.6 lbs of thrust in the normal operations mode, and 2.8 lbs of thrust in the backup operations mode. Rotational torques are the same for the prime and backup modes. For multi-axis commands up to 6 thrusters can be firing simultaneously.

The automatic attitude hold (AAH) capability of the MMU allows the crewmember to maintain attitude in any or all of the axes of rotation. The MMU control logic automatically fires thrusters as required to hold a position within a deadband of $\pm$0.5 to $\pm$2.0 degrees (premission selectable) in any rotational axis, as sensed by the rate gyros. Drift rates across this deadband (if, for example, the crewmember is relatively still while inspecting or photographing a payload) are on the order of 0.02 deg/sec (see Fig. A-8).

In the AAH mode, highly developed control logic incorporating limb motion filters and limited minimum impulse thrust repetition rates allows a tight limit cycle deadband that is relatively insensitive to large crewmember limb motions and is fuel conservative in the presence of these cyclic disturbance torques.

Three-axis attitude hold can be commanded during translation in any axis. Attitude hold can be inhibited independently in the roll, pitch or yaw axes when the crewmember inputs via the RHC a manual rotation command in that axis. For example, if the MMU is in AAH and a 180° yaw is

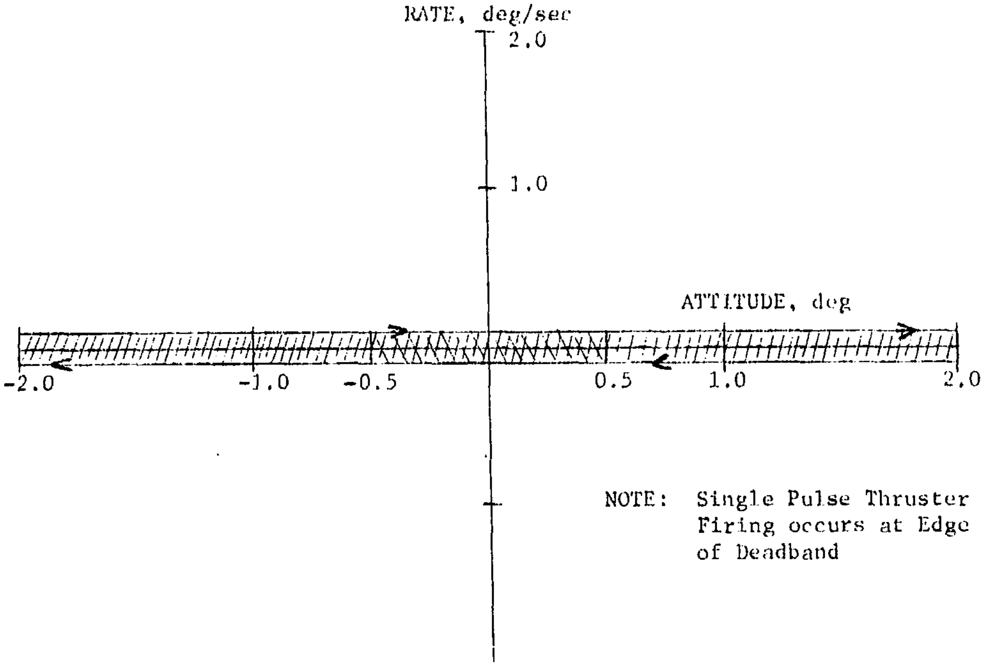


Figure A-8 AAH Limit Cycling with No Disturbance Torques

required, a 1-second yaw command can be input at the hand controller to begin the maneuver at approximately 10 deg/sec. During the rotation in yaw, attitude will be maintained in the pitch and roll axes. After approximately 17 seconds the crewmember can either issue another 1 second command to cancel the yaw rate, or can press the switch on the RHC to command automatic attitude hold in all axes again.

These MMU flight characteristics allow the EVA crewmember to translate, perform inspection or photographic surveys, assist in payload operations or servicing, and the variety of other tasks listed in Section 2.0. Specific tasks are discussed in more detail in Section 6.0 of this guide.

A.4 <u>MMU Flight Instrumentation</u>

The MMU provides instrumentation signals to the EMU which process the information and provides visual displays to the EVA crewmember on the top horizontal surface of the EMU displays and controls module (DCM) mounted as a chest pack on the pressure suit. Normally, the amount of propellant remaining in the MMU (systems A and B) is displayed continuously. The crewmember also has the capability to select for display either the battery power remaining (systems A and B) or GN_2 tank pressure (A and B). These two displays are part of a sequence of parameters which provide information on the EMU/MMU status.

The crewmember also receives an audible tone as a thruster cue, and a caution and warning tone when the pressure difference between GN_2 tanks exceeds 300 psi, when the power remaining in the lowest battery reaches 20%, and when GN_2 quantity in either tank drops below 10% (status tone) and 5% (warning tone). Table A-1 summarizes the instrumentation displays and controls available to the crewmember in the MMU.

Table A-1 MMU Instrumentation Controls and Displays

Control	Display	Location
MMU Main Power	---	Two switches on MMU left control arm
---	Ampere-hours remaining - Systems A and B	EMU DCM (on request, or if out of limit)
Translational Hand Controller (THC)	---	Left control arm of MMU
Rotational Hand Controller (RHC)	---	Right control arm of MMU
Rate Gyro Power	---	Two switches (Battery A & Battery B) at MMU right control arm
Automatic Attitude Hold	---	Button on RHC
Ancillary Power	---	Two switches--one on top front of each tower
Strobe Light Power	---	Switch--outside of left tower
Floodlight Power	---	Switch--outside of right tower
---	GN_2 quan. remaining (Sys. A & B)	EMU DCM (continuous)
---	GN_2 pressure (Systems A & B)	EMU DCM (on request, or if out of limit)
---	Thruster cue (audible tone)	EMU communications carrier
---	Tank ΔP - warning tone	EMU communications carrier
---	Low power - warning tone	EMU communications carrier
---	GN_2 quantity low - status and warning tones	EMU communications carrier
Thruster Cue Off	---	One switch at TBD

APPENDIX B - EVA GUIDELINES

For information purposes, the following EVA guidelines and constraints (excerpted from JSC 07700, Volume XIV) are presented.

a. EVA operations will be developed using the capabilities, requirements, definitions, and specifications set forth in JSC 10615, *Shuttle EVA Description and Design Criteria Document*.

b. EVA operations are normally performed by two EVA-trained crew members. However, one-crewmember EVA is also a viable option.

c. Planned EVA periods should not exceed one 6-hour duration per day (*excluding* the time required for EVA prep and post activities). This does not preclude multiple EVAs of shorter duration.

d. EVA may be conducted during both light and dark periods.

e. EVA will not be constrained to ground communication periods.

f. Payloads requiring EVA operations must size access corridors and work areas to allow the EVA crewmember to perform the required EVA tasks safely and with adequate mobility.

g. An EVA egress path into the cargo bay, 4 feet minimum length (1219 mm), must be available adjacent to the airlock outside hatch. Payloads which infringe into this area must be jettisonable to allow for contingency EVA operations.

h. Payload and support mechanism design must not inhibit unobstructed EVA access to potential Orbiter contingency work areas in the cargo bay.

i. Neither payload location in the cargo bay nor EVA payload operations will inhibit a rapid return of the EVA crewmember to the airlock hatch from any location in the bay. Airlock repress to a viable pressure must be possible within 30 minutes following the EVA terminating contingency.

j. The size of the airlock, tunnel adapter, and associated hatches limits the external dimensions of packages that can be transferred to or from payloads to 22 in. (558 mm) x 22 in. (558 mm) x 50 in. (1,270 mm) for unsuited operations and to 18 in. (457 mm) x 18 in. (457 mm) x 50 in. (1,270 mm) for pressure-suited operations. Package sizes exceeding these dimensions shall be evaluated on an individual basis.

k. EVA crewmembers will not operate in, on, or near free-flying satellites or payloads which have an excessive rate of rotation about any axis. The maximum rotational rate and mass combinations that are compatible with MMU operations are TBD.

Each Orbiter mission provides equipment and consumables for 2 two-crewmember payload EVA operations, each lasting six hours nominally. These operations can utilize the MMU on a preplanned (planned prior to mission) basis. Ordinarily the MMU is carried in the Orbiter vehicle only on those missions for which MMU or EVA operations have been identified before launch. MMU operations can be conducted with a single unit, or with two units operating together.

APPENDIX C - REFERENCE DOCUMENTS

Number	Title	Source
MCR-78-500	Manned Maneuvering Unit Design and Performance Specification	Martin Marietta
JSC-07700, Vol. XIV	Space Shuttle System Payload Accommodations	NASA/JSC
ICD2-19001	Shuttle Orbiter/Cargo Standard Interfaces	NASA/JSC
JSC-10615	Shuttle EVA Description and Design Criteria	NASA/JSC
JSC-11123	Payloads Safety Guidelines Handbook	NASA/JSC
JSC-10532	Manned Maneuvering Unit Operational Requirements	NASA/JSC
JSC-07700-14-PIV-01	Space Shuttle System Payloads Interface Verification General Approach and Requirements	NASA/JSC
SVHS 7800	Extravehicular Mobility Unit Design and Performance Requirements Specification	Hamilton Standard
ESA SLP/2104	Spacelab Payload Accommodations Handbook	NASA/MSFC
	Space Transportation System User Handbook	NASA/Hdq.
	Interim Upper Stage Users' Guide; Spinning Solid Stage Users' Guide	NASA/MSFC
	Long Duration Exposure Facility (LDEF) Guide for Experiment Accommodations	NASA/LaRC
	Multimission Modular Spacecraft Users' Guide	NASA/GSFC
K-STSM-14.1	KSC Launch Site Accommodations Handbook for STS Payloads	NASA/KSC
	VAFB Ground Operations Plan	SAMSO
JSC 11803	STS Flight Planning	NASA/JSC